1976 annual report on Montana's Involvement in the High Plains Experiment

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Montana's Involvement in the

HIGH PLAINS EXPERIMENT (HIPLEX)

by

Water Resources Division

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CHAPTER I

INTRODUCTION

Richard Moy

The science of inducing rain from cumulus clouds during the growing season on the semi-arid High Plains is not well understood. Many uncertainties exist concerning the efficacy and predictability of weather modification programs as well as their impacts on natural and agricultural ecosystems and the people who live there. To reduce these uncertainties, the Bureau of Reclamation, through the Division of Atmospheric Water Resource Management (DAWRM) initiated the HIgh PLains EXperiment (HIPLEX) as part of their Project Skywater.

The objective of HIPLEX is to develop an effective weather modification technology, scientifically and socially acceptable for precipitation management on the High Plains. Three experimental sites were chosen representing the northern (Miles City, MT), central, (Colby-Goodland, KS), and southern High Plains (Big Spring-Snyder, TX); with Miles City as the primary site for initial phases of the program. This project, coordinated and primarily funded by the Bureau of Reclamation, is a cooperative research endeavor. As such, it involves various groups and governmental agencies, including the State of Montana through its Department of Natural Resources and Conservation (DNRC).

Montana's primary role in HIPLEX is to assess the beneficial and deleterious impacts of increased growing-season rainfall on agriculture and natural ecosystems, as well as on the economy and society. In addition, DNRC has assumed the responsibility of cooperating with DAWRM in measuring rainfall and evaluating changes in rainfall that HIPLEX might cause. The latter entails designing, constructing and operating a surface precipitation measurement network, participating in the measurement of rainfall by radar, and analyzing meteorological data pertaining to rainfall.

In 1975 the DNRC staff devoted most of its time to designing, constructing and operating a surface rain gage network as well as constructing 31 native rangeland experimental sites. Detailed discussions of these tasks and studies, as well as a literature review on the probable effects of weather modification on native range ecosystems, are provided by Boatman et al. (1975), Boatman (1976) and Perry (1976).

This report covers, in Chapters II through IV, the accomplishments of the DNRC staff in 1976: meteorological activities are discussed in Chapter II; preliminary reports of the four agro-ecological studies are presented in Chapter III; and general activities are covered in Chapter IV.

Chapter II is divided into precipitation measurement, precipitation data management and radar operation. The precipitation measurement section outlines

DAWRM's criteria and DNRC's rationale for locating the 1976 surface precipitation network northeast of Miles City. The construction and operation of the network and the training of service technicians are also discussed. It further describes various problems associated with the 1976 field season, and recommends ways to reduce them in the future.

In the precipitation data management section, the procedures used to transform and store the 1976 precipitation data in the CYBER computer are discussed; differences in the reduction process of the 1975 and 1976 data are elaborated. Procedures to access the 1975 and 1976 rainfall data from the CYBER computer are also outlined. Cloud photography data and the 1975 and 1976 rainfall data are compared, to determine both the total network rainfall representative of various cloud types and the rainfall distribution produced by various cloud types.

The radar operation section describes Montana's role in maintaining and operating the Skywater SWR-75 radar system and the collection and analysis of radar data. Problems associated with radar operation and data reduction procedures are emphasized.

Four agro-ecological studies are described in Chapter III. The first study is a joint venture between DNRC and Dr. Larry White of the Agricultural Research Service, Northern Plains Soil and Water Research Center, Sidney, Montana. The other three studies were conducted under the supervision of Dr. Tad Weaver of Montana State University.

The first study compares native-range species composition by basal area in 23 permanent plots before and after an extended period of above-average precipitation. In the second study, the water-holding capacity of barley at different phenological stages is determined from 0.8 cm showers. The third study determines the effects of 0.25 to 1.25 cm summer showers on water potentials of barley and major native range grasses. This study notes some interesting preliminary results regarding high water stresses and discusses possible effects of summer rain showers on photosynthetic rates of various plants. The fourth study attempts to determine limiting factors that affect dormancy of five grass genera--two warm-season and three cool-season. Limiting factors may include drought stress, day length, flowering and the timing of rainfall.

Chapter IV covers general activities such as the local Advisory Committee, clerical tasks, and facility maintenance.

The personnel involved in Montana's HIPLEX program who made this report possible are listed on the organization chart in Appendix I.

CHAPTER II

METEOROLOGICAL ACCOMPLISHMENTS

Precipitation Measurement

Larry Holman and Marty Lynam

A). Facility Development and Installation

One of the primary objectives during 1976 was to develop and operate an expanded surface precipitation measurement network. Basic criteria for its design, provided by DAWRM, included:

(1) Locate the surface network at mid-range from the SWR-75 radar. The primary operating range for the SWR-75 radar is 25 to 150 km.

(2) Establish a rain gage density of 15.5 km^2 per gage (6 mi^2 gage) within the network. This density specification was decided jointly by DAWRM and DNRC. A literature review conducted prior to the 1975 field season suggested that the appropriate network density for analysis of precipitation data was between 10 and 26 km^2 (4-10 mi^2) (Huff et al, 1969; Woodley et al, 1974; Huff, 1969). In addition, work by Amos Eddy (1975) indicated that 1 gage per 6 mi^2 was desirable.

(3) Place three cluster sites 8 km (5 mi) upwind of the contiguous network to the northwest, west, and southwest and 3 cluster sites 16 km (10 mi) downwind of the contiguous network to the northeast, east, and southeast (see Fig. II-1). The purpose for these cluster sites, as proposed by the Illinois State Water Survey (ISWS), was to provide an independent evaluation of the radar-rainfall relationships derived from the contiguous network.

(4) Collocate Belfort gages with one-fourth of the LANDSAT telemetry gages and with all "memory" gages, which transmit data to an airborne receiver. (These gages are described in the 1976 Miles City HIPLEX operational plan). The total number of Belfort gages initially collocated was 33 (13 LANDSAT + 20 memory).

(5) Expand the 1975 surface network and continue with a circular-shape.

(6) Do not extend the network into areas where radar ground clutter had been observed from the previous year's data. This necessitated elimination of certain areas from site consideration as shown in Fig. II-1.

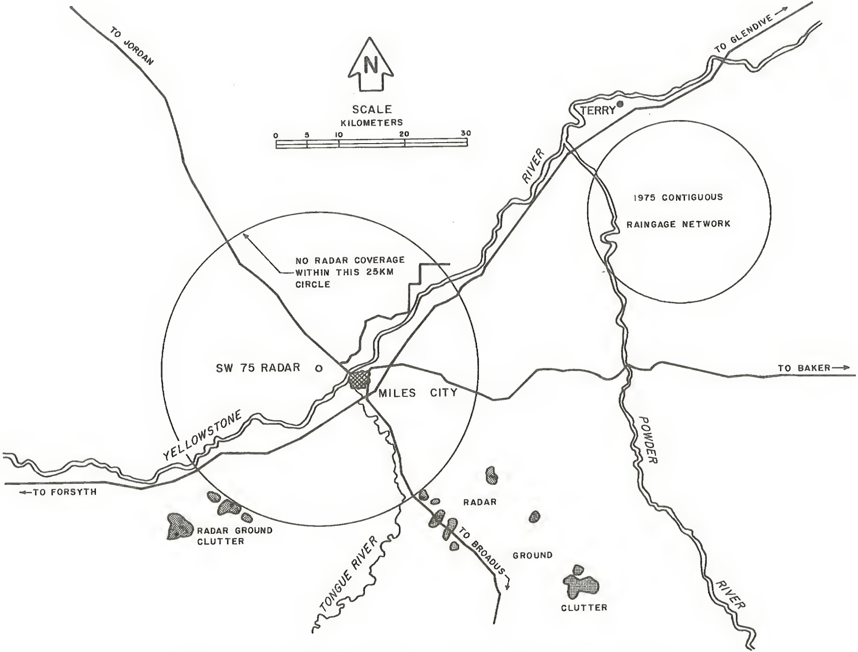


Figure II-1. Ground clutter from the 1976 SWR-75 radar data

These criteria limited the location for the network. Other factors which influenced the final decision included:

(1) Continued use of existing facilities. The 1975 field program installed and operated a network of 55 rain gages southeast of Terry, Montana (Fig. II-1), and a line network of 15 gages extending northeast of Miles City for approximately 100 km. Many of these facilities could be used again saving on additional construction and installation expense. Fifty-three of the former 1975 sites were retained for 1976 field use. All other sites were either removed or retained for ecological research purposes. To continue with the existing hexagonal configuration, (see Boatman et al, 1975), an equivalent hexagonal interfacing was sought.

(2) Reasonable access to new gage sites. For the 1975 field season all but three sites were located within 0.5 km of the originally designed positions. To continue to meet this criterion an area was sought with limited relief, less than rugged terrain, and an above average number of roads and trails.

(3) Shorter travel distances to network sites to reduce travel time and to increase available service time. Sites were sought closer to headquarters and major travel arteries.

(4) Area with a relatively high mean growing season rainfall and limited horizonal gradient. These criteria, important in locating the 1975 network, continued to be important in 1976 for we wanted to maximize the number of test cases available for analyses.

(5) Locate the rain gage network in part of the area covered by the Baker radar scan. A second C-band radar at Baker, Montana, was scheduled for operation during the 1976 field season. It was desirable to provide surface rainfall data to compare with radar measurements from both the Miles City and Baker radars.

(6) Willingness of the agricultural community to cooperate and participate in the program. Very few citizens near Miles City were hesitant or antagonistic toward the program. As a result, almost all areas were considered equally good for site locations.

(7) Topography representative of the entire study area. Many areas near Miles City offer a wide geomorphological spectrum from valleys and benches to flatland and badland terrain. Therefore, the need for inclusion of a diverse selection of geomorphological features in the network design was not a problem. (However, the Yellowstone River, the Powder River and other prominent streams in the vicinity often created an access problem).

Preparations for the 1976 rain gage season were initiated in January, 1976.

The primary tasks were to design a workable network configuration and to locate potential rain gage sites. Principal factors in the design and location

of the network previously discussed are summarized in Table II-1.

TABLE II-1

Criteria and Advantages of the Precipitation Network Design

Bureau of Reclamation criteria	1. Center of network at mid-range of radar 2. Density of rain gages = 15.5 km^2 3. Eliminate ground clutter from network 4. Expand area of network 5. Collocate Belforts with telemetry gages 6. Cluster sites as part of design
Additional criteria by DNRC	1. Continued use of existing facilities 2. Locate each gage within 0.5 km of designated location 3. Minimize travel time 4. Overlap with Baker radar coverage 5. Cooperation with agricultural community 6. Above average seasonal precipitation and limited horizonal gradient 7. Representative topography

Locating the network for good access and reasonable travel considerations would be best accomplished in the area northeast of Miles City. Other criteria favoring this area included additional radar coverage from Baker, availability of existing facilities, above-average seasonal precipitation and varied topographic characteristics.

Disadvantages for this area included the occasional radar ground clutter problem and prominent physical barriers such as the Yellowstone and Powder Rivers.

The network configuration remained a hexagonal grid. A 15.5 km^2 (6 mi^2) gage density and a circular shape characterized the network. Although an elliptical network was considered in planning, uncertainties regarding preferred storm tracks, dictated a circular network.

Expansion of the network was generally to the north and west of its 1975 location to allow for shorter travel time and to stay within the reasonable radar mid-range. Fifty-three of the original 1975 sites were incorporated into the network. Fifty-six new sites were established as part of the contiguous network and 18 additional new sites were set up in six clusters of three gages per cluster.

In all, 127 sites were established. After deciding the network location and plotting the individual site locations within a grid of one site every 15.5 km^2, permission to locate the 74 new sites was sought. This task was finished in March.

Materials, equipment and supplies for erecting fences were requisitioned in January. All sites requiring fences were scheduled for construction in late March and early April. Fence design was modified from the previous year to hasten construction and to follow requirements set forth by the Bureau of Land Management. A sketch of a typical fenced site is provided in Fig. II-2. Photographs of typical sites with and without a telemetry rain gage are in Figs. II-3 and II-4, respectively.

Beginning in March, 69 sites were fenced. The remaining five new sites did not require fencing or were located within existing fenced areas (e.g., yard, hay corral). Discontinued sites from 1975 were dismantled. All Belfort rain gages were calibrated and made operational in April; at this time all gage clocks were tested in the laboratory for at least one week.

Ninety Belfort rain gages were installed and being rountinely serviced by April 30, 1976; 18 were located within cluster sites and 72 within the contiguous network. Of those in the contiguous network, 56 were at new sites and 16 at previous sites.

By the latter half of May it became obvious that the LANDSAT gages were not providing reliable data. As a consequence it became necessary to collocate a Belfort gage at each site within the contiguous network. The Bureau of Reclamation therefore decided to transfer the 18 Belfort rain gages in the cluster sites to the circular network. In addition, 19 more Belforts were made available from various sources and placed within the contiguous network to make a full complement of 109 Belfort rain gages (Fig. II-5).

Wedge gages and hail pads were collocated with the Belfort gages as shown in Figs. II-2, II-3, and II-4.

B) Operation

Training

Before the start of the 1976 field season service technicians were trained to perform the following duties:

(1) Site Service. These procedures, developed during the 1975 field season were used in 1976 to ensure that all data were gathered correctly at each rain gage site, and that the instruments were properly "set" to record data for the next seven days. Fig. II-6 shows the "Belfort Service Check List," they followed. By using this check list, human errors were minimized.

(2) Field Calibration of Belfort Rain Gages. Initially, two service technicians were instructed in calibrating rain gages in the field (in the event of damage to the gage) and replacing the chart-recording pen. By the end of the operational season most of the service technicians could calibrate gages.

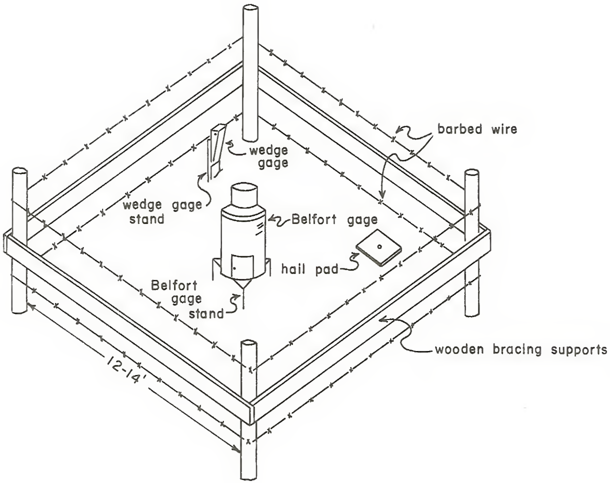


Figure II-2. Sketch of a typical rain gage site.

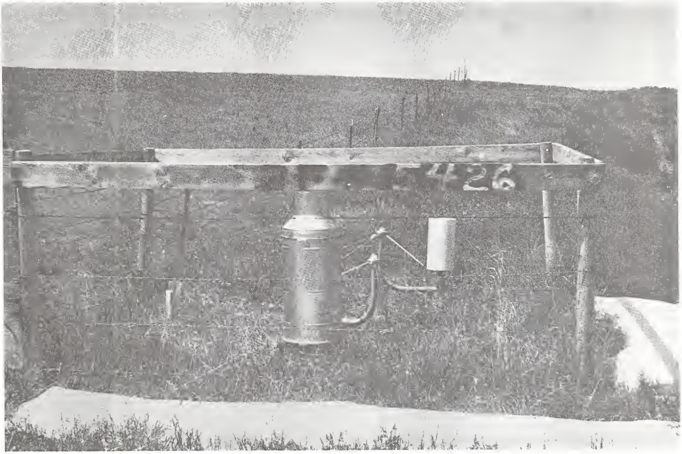


Figure II-3. Rain gage site with a telemetry rain gage, used during the 1975 and 1976 seasons. In the center of the enclosure is the Belfort rain gage with a hail pad located to its left rear. To the left of the hail pad is a wedge gage. Near the right center of the enclosure is the telemetry rain gage with its transmitting antenna. Outside the fence to the right and in the foreground are two fluorescent panels.

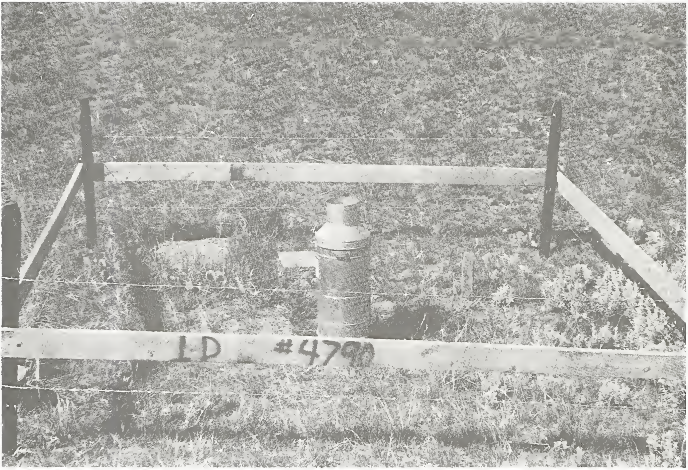


Figure II-4. Rain gage site used during the 1976 season. The Belfort rain gage is at the center of the fenced enclosure, with a hail pad located behind it and a wedge gage to its right.

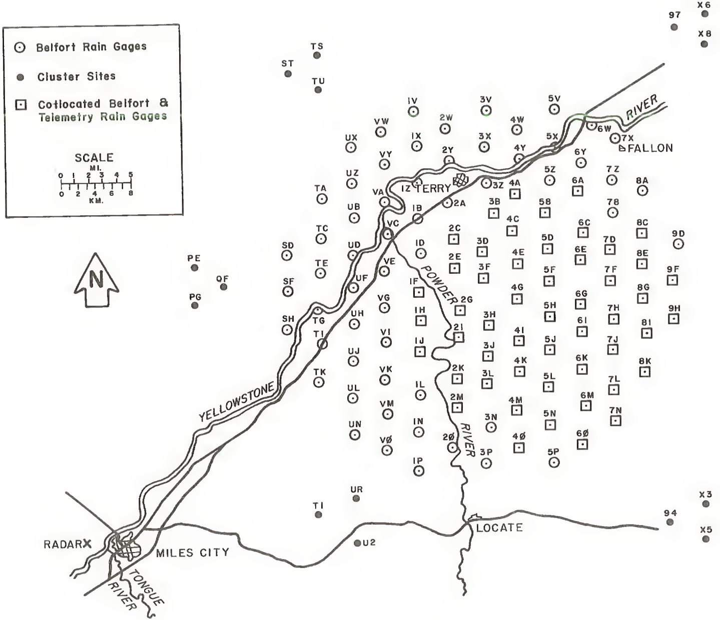


Figure II-5

1976 HIPLEX RAIN GAGE NETWORK FOR MONTANA

Figure II-6

BELFORT GAGE SERVICE CHECK

Gage #______________ Site #______________________

Day of Week _________________

Date _____/_____/1976

Arrival Time _____________ hrs. MDT

Name of Observer ____

---

1. Is pen inking? Yes_____ No _______
2. Note recording of water level at current time. _______-________inches
3. Recorder time ________:_______hrs. MDT

   Actual time _______:________hrs. MDT
4. Note current time ______date________gage reading_______and observer______on old chart.
5. Remove chart_______Wind the clock______OK
6. Add or subtract water to bucket to bring to proper level
7. Install the new chart. Note starting time____date_____location_____

   gage reading_____ and observer_____ on new chart. Is clock wound? Yes___No___
8. Refill in-pen bucket and make certain pen is inking______OK
9. Set time to present and note time here______hrs. MDT
10. Remarks ____

    ____

    ____
11. Is it presently raining? Yes___ No___

    Has it been raining during the last day? Yes___ No___

    If yes was the rain light____moderate____intense____?

(3) Operations. Because access to many of the sites required off the road travel through very rugged terrain, maintenance and safe driving practices of four-wheel drive pickups were emphasized, in addition to proper maintenance of the engine, drive train and tires. Three-wheel all-terrain cycles were used in areas of very rough terrain where road conditions, or request of the landowner, prevented the use of pickups. Since successful riding of three-wheel cycles required special operating skills, training time was devoted to their operation.

(4) Radio Communication. UHF business-band mobile radios, provided by the Bureau of Reclamation, were installed in the pickups and at HIPLEX headquarters. During the training and operational periods, proper radio procedure was practiced in accordance with FCC regulations and recommendations. Radio communication between vehicles and the HIPLEX headquarters increased the efficiency and coordination of daily activities.

Operating Procedures

Throughout the operational season each site was visited by a service technician on a weekly schedule to collect data and to service the equipment. Each technician was assigned four routes per week, with from five to ten sites per route depending upon access (pickup or three-wheel), terrain conditions, and travel distance. Routes were structured so that one technician driving a pickup could transport another technician and a three-wheel cycle to the field near the three-wheeler's route and then meet him later in the day. This "piggy-back" technique enabled greater economy in the use of vehicles and resources.

Upon arrival at each site the technician followed these procedures:

(1) Belfort Rain Gage Service. The technician compared the current time indicated on the rain gage chart with the correct time as indicated on his watch (set daily against the National Bureau of Standards time standard as transmitted by radio station WWV). If the chart-drive clock error was no greater than ± 5 min, no action was taken. But if the error was greater than ± 5 min, the regulator inside the clock was adjusted to bring it within required accuracy limits.[1] If the clock had stopped at some point during the week, note was made of this in the operator's site log book. A running field log was also kept on the accuracy of each clock to enable the technician to notice any trends.

The trace of the chart pen was then checked for proper marking. If the pen was skipping, it was cleaned and restored to operation. If cleaning did not correct the problem, the pen was replaced. Notations were made on the Belfort Gage Service Check (Fig. II-6) to indicate pen replacement and to alert the Field Manager that a minor change in calibration might have occurred due to the new pen dimension.

1. Instructions for Chart Drive Assemblies. 1960, Baltimore, p. 5. Belfort Instrument Company.

When the clock and pen had been inspected, the old chart removed from the drum, and the clock wound, a new chart was installed. The time of removal was indicated on the old chart, and the time of installation was indicated on the new chart. Sufficient water was added to the gage bucket to raise the water level to about the 2.0 in mark. This allowed the pen trace to gradually spiral down as the water evaporated, thereby easing the data reduction process. (Because the drum rotated every 24 hours, seven traces were on a chart between weekly service).

The gage was then serviced in accordance with the Belfort "Operating Manual for Weighing Rain Gages"[2] thus preparing it for a week of operation.

(2) Wedge Gage Service. The precipitation amount of the past week was recorded on the "Belfort Service Check Sheet." The used wedge gage was emptied and replaced with a clean gage containing 0.02 in of diesel fuel or aircraft hydraulic fluid to suppress evaporation. The used gage was then returned to the HIPLEX office for cleaning.

(3) Hail Pad Service. The hail pad at the site was inspected for hail strikes and/or damage, and replaced if necessary. Vegetation within 1 m of the hail pad was trimmed to ground level to prevent deflection of hail by the vegetation.

(4) Site Inspection. The physical condition of the fence and gage was checked, and, if necessary, repairs were made. If the service technician could not make the repairs, they were noted in the log book.

Once the above steps were finished, the technician checked the notations in his log book to ensure that nothing was overlooked during the site service. All abnormalities at the site were noted in the "remarks" section.

Upon returning to the HIPLEX office after completion of the day's route, service technicians gave the data and log sheets to data clerks for reduction and filing. The Field Manager then reviewed the log books and scheduled any maintenance that was necessary, such as replacing the chart drive clocks when they showed large errors during the past week or had stopped. As a result of prompt replacement of faulty clocks and other repairs, the percentage of proper gage operation days compared to the total number of days for the 1976 field season exceeded 91 percent. The average clock error was about 6 min per week.

Durability and Accuracy of Chart Drive

At the end of the operational season a summary was compiled for each chart-drive clock, which included the total possible operating time, the actual operating time and the total seasonal error. Table II-2 summarizes these data.

2. Operating Manual for Weighing Type Rain Gages, Catalog No. 5-780 Series. 1960, Baltimore. Belfort Instrument Company.

TABLE II-2

1976 Clock Reliability and Accuracy

Clock Type	No. of Clocks Used	I Potential Clock Operation Time (Clocks x days)	II Downtime (Clock x days)	III Percent Operating Time (II/I) (100% - II/I)	IV Total Error for season (Clocks x Min)	V Days of Clock Operation (Clocks x days)	VI Average Error (IV/V) (min/day)
Electric (1) (battery)	72	2755	267	90.3	3160	2488	1.27 (9 min/week)
Tall Mechanical (2)	41	2044	290	85.8	1143	1754	0.65 (5 min/week)
Short Mechanical (3)	28	5452	361	93.3	3415	5091	0.67 (5 min/week)
All Clocks Combined	141	10251	918	91.0	7718	9333	0.83 (6 min/week)

1. Clocks manufactured by Kingmann-White Company, Placenta, California, using a 3 volt, dry cell power supply.

2. An older Belfort Instrument Company mechanical clock with the chart cylinder an integral part of the clock housing.

3. A Belfort clock of later manufacture (Manufacturer's Catalog No. PL-14252).

Percent operating time (efficiency) and average error per week for the three types of chart drives are indicated for the 1976 network. The average error (shown in column VI) exceeds the desired maximum of ±0.7 min per day (5 min/week) for all mechanical and electric clocks. However, the average error for the two types of mechanical chart-drive clocks was within the desired limits.

Laboratory Calibration

The 109 recording rain gages were calibrated and repaired as necessary in the laboratory before being installed in the field. The procedures in the Belfort Operating Manual,[2] the Belfort Calibration Instructions[3] and procedures prepared at Montana State University (Appendix II) were used to calibrate the gages to within the tolerances set forth in Table II-3. At a chart reading of 0.0 in, an accuracy of 0 ± 0.03 in was considered sufficient because the recorded level did not reach zero after water was added to the gage bucket each week. In addition, since the probability of a weekly rainfall of 6 in was low and a calibration of 6 ± 0.02 in difficult to achieve at a chart level of 6 in , an accuracy of 6 ± 0.05 in. was considered sufficient.

TABLE II-3

Calibration Tolerances for Weighing Rain Gages

Chart Level (in)	Acceptable Reading (in)
0	0 ± 0.03
1	1 ± 0.02
2	2 ± 0.02
3	3 ± 0.02
4	4 ± 0.02
5	5 ± 0.02
6	6 ± 0.05

Each chart-drive clock was pre-tested for at least seven days, prior to installation, and the accuracy of each clock adjusted within ± 5 min per week.

Field Calibration

All rain gage calibrations were checked three times in the field. Immediately after installation, each rain gage was checked and the calibration adjusted, if necessary, to ensure that the transporting and handling of the gage did not disturb its accuracy. Starting in late June and continuing into July, a mid-season calibration check was also made. During this time it was noted that errors in readings at each whole-inch chart level seldom exceeded ±0.02 in. The weekly preventive maintenance apparently was successful in reducing errors for the three-month period of the field season. Upon removal of the rain gages from the field, a

3. Calibration Procedures, Manufacturer Part No. 8051. 1960, Baltimore. Belfort Instrument Company.

final calibration check was made. In almost all cases the readings were found to be within acceptable limits.

Any deviation in accuracy from specified limits for each gage was used to calculate a linear regression which was entered into the computer system. This information was used to correct the original data before any analysis.

End of Season

Starting August 2, 1976, all gages were removed from the field and prepared for winter storage. The fence wires at each site were tightened and the wooden members of the fence were given a coat of Four-Pound Penta (PCP-2) Concentrate, a wood preservative.

Problems

More problems were encountered with the reliability of the battery-powered chart-drive clocks than with the mechanical clocks. Problems with the mechanical clocks were two fold; either the clocks were slightly more than ± 5 min off the correct time when checked, or were stopped due to some malfunction. The battery-powered clocks, on the other hand, stopped less often but had a larger error; occasionally as much as several hours per week. The causes of this error are not known, but may be due to environmental conditions, such as cool temperatures, dust, etc.

C) Discussion and Recommendations

Field season activities lasted from mid-December, 1975 through August, 1976. The network was designed and materials procured in January. The actual field phase began in March with siting of gages. Further field activities included construction of sites, installation of gages, routine maintenance of equipment, collection of rainfall data and dismantling of facilities. It was during the operational season that problems in the network became apparent.

Problems associated with field activites evolved from several areas;

1. equipment operation,
2. personnel management,
3. weather considerations, and
4. program design and scheduling.

The most obvious problem was equipment failures. Several of the available rain gages had been used for many years previously on other projects. Consequently, they showed considerable wear and many of these gages required initial repair. Once repaired, each Belfort unit was expected to work satisfactorily for the duration of the season, however, breakdowns occasionally plagued the operation.

Operational problems contributing to inaccurate data records generally revolved around the gage apparatus. This includes two systems, the chart drive and the weighing mechanism.

Breakdowns attributed to chart drive included;

1. clock stoppages,
2. timing inaccuracies,
3. improper pen inking,
4. improper shielding from rain and subsequent wetting of chart, and
5. chart tearing or unhinging.

Clock stoppage and timing inaccuracies were frequent. These breakdowns were often the result of; failure to wind clocks, poor gear meshing, chart clips of excessive length creating a drag on the system, dust or dirt contamination within clocks, inadequate power supply, broken wires, or extremes in temperature and humidity.

Pen operation which contributed to the failures included; improper alignment of pens, dirty pens, or pens poorly fastened to arms.

Inadequate shieldings, as well as chart tearing or unhinging, were minor problems.

The weighing mechanisms generally operated satisfactorily. However, normal wear and improper anchoring of a gage to its stand caused some problems. During windy periods the latter would sometimes result in a continuous vibration in the recording trace, or in the pen arm oscillating to an extreme position, both of which caused the pen to lock. This problem could be severe during very windy periods. Occasionally, a screw or bolt on the weighing apparatus would loosen and create problems.

Human errors were obvious when servicing was not completed satisfactorily. Inadequate performance of a few personnel initially hindered the operation, but this was quickly remedied.

The role of weather in a field program causes obvious and unavoidable delays and failures. Contingencies were built into the operational plan to recover from these uncertainties. On several occasions service missions on specified routes were interrupted or postponed because of bad weather, but almost all of them were completed the next day. The data loss due to inaccessible roads was minimal.

Some of the aforementioned problems were unavoidable. However, considerable improvements in efficiency of operation and data collection can be achieved. The following recommendations are suggested to reduce gage failures and to increase the quality and quantity of rainfall data.

(1) Prior to field installation;

  a) Check all timing adjustments. These adjustments must have a tolerance of no less than one-half of that expected under field conditions.

  b) Further check all chart-drive systems under field conditions for a minimum period of one month.

  c) Thoroughly examine gear meshing, alignment, the lengths of chart clips and continuity of wires (electric clocks) before the field season.

d) Check batteries and ascertain capacity of power supplies.

(2) Once a system has been tested and shown to work satisfactorily, its components must remain as part of a unit for the duration of the field season.

(3) Transport the equipment with extreme care. Remove the clocks from the gages and pack each instrument separately. Make sure all instruments are secured and cushioned before transporting.

(4) To reduce human errors, extensively train the service technicians during the pre-operational phases of the field program. A written copy of guidelines describing operation maintenance, service repair and data collection should be provided and taught to all technicians. They should be made fully aware of the data reduction process so they can better appreciate the problems associated with data loss; initially being required to share in the data reduction activities.

(5) Assign each technician specific responsibilities for various phases of the field program. They must be made accountable for their performance.

(6) Store the recording rain gages in a dust and dirt proof area to protect the clock apparati.

(7) All systems should be as congruent as possible. Utilization of several different types of clocks, buckets and pens should be eliminated; conforming to one standard reduces repair and maintenance.

Precipitation Data Management

Joey Boatman

A) Introduction

After collecting precipitation data, they must be translated into a form compatible for analysis. This was accomplished with the 1975 precipitation data (see Boatman, 1976) and these procedures, with some additions, were repeated with the 1976 precipitation data.

After translation, a preliminary analysis was undertaken for both the 1975 and 1976 precipitation data to determine the natural distribution of summer rainfall and to find the frequency of rainfall occurrence by cloud types.

This section discusses the reduction and storage procedures and analyses performed.

B) Reduction Process

Procedures for processing 1975 rainfall data are discussed by Boatman (1976). These procedures were duplicated with the 1976 rainfall data, but with the following improvements. Data were:

(1) computerized within eight days after collection, resulting in a more error-free data base. In 1975, two data clerks were trained in data reduction techniques during the operational season resulting in a two month delay between data collection and data translation. In 1976, these trained data clerks were employed to transfer data from rain data charts to computer coding forms resulting in a more accurate and orderly data transferral.

(2) placed in a new format (during the processing phase) consistent with the rainfall data from other HIPLEX sites. A coded storage format of rainfall data consistent to all sites in HIPLEX was established and is outlined below.

L SI Y M DA Q (DDD.........DDD)

where;
- L = site location (in Montana's case "M")
- SI = site number
- Y = year
- M = month
- DA = day
- Q = quarter of day, with quarter 1 = 0000-0545; 2 = 0600-1145; 3 = 1200-1745; 4 = 1800-2345. (all times are GMT)
- DDD = one 15-min rainfall total, there are 24 rainfall totals or 6 hours of rainfall data in each computer record.

This data storage format allows the 96 fifteen-minute rainfall totals generated daily by each rain gage to be placed on four 80 column punch cards. All 1975 rainfall data have been changed to this format.

(3) computerized only during the period of radar operation. During March-April 1976 it was felt that the surface rainfall network would be used primarily as a calibrating tool for the Skywater Radar (SWR-75) in estimating rainfall at the ground. For this reason it was decided (Super, 1976) to encode surface rainfall data only during the period of radar operation (1730-0800 GMT). The remaining 1976 rainfall data are available on the original rain gage charts if subsequently needed.

(4) converted to Greenwich Mean Time (GMT). All HIPLEX data prepared for analysis were placed in Greenwich Mean Time. For convenience, all rainfall data including 1975 data were collected using local Mountain Daylight Time (MDT) but converted to Greenwich Mean Time during final computer processing.

(5) placed in a plotted form which is accessible on standard microfiche. A data plotting program was made available at Montana State University whereby daily rainfall totals at each rain gage are displayed. Daily plots of 1975 and 1976 rainfall data were produced using this program. Examples of the plotted data for both years are shown in Figs. II-7 and II-8. Data from 183 days in 1975 and 111 days in 1976 are displayed, as in Figs. II-7 and II-8, on two microfiche.

C) Storage and Accessability

This section is intended not only as a summary of 1976 task accomplishments but also as an accessing aid for those wishing to use the 1975 and 1976 rainfall data in their analyses.

Since the rainfall data accumulated occupies a significant amount of computer space and is costly to maintain on the CYBER 74-28 computer system, it has been placed on two 9-track magnetic tapes. The basic structure of the rainfall data on the tapes is shown in Fig. II-9.

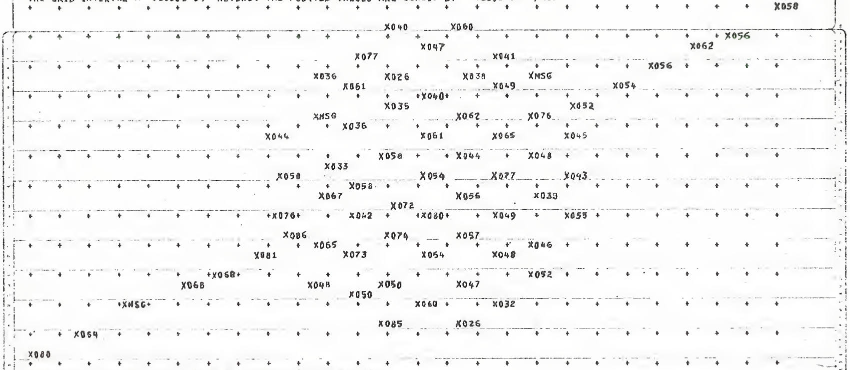
Two computer files have been developed which, when executed, place the 1975 and 1976 rainfall data in the CYBER 74-28 computer's memory. Their names are RGET75 and RGET76 and they may be found stored in account ER1200I. A listing of each file is shown in Table II-4.

As an example, if one wishes to use the 1975 rainfall data and desires it to be placed on the computer for analysis, the following procedure should be followed.

(1) Obtain a copy of file RGET75 using the computer command "GET,RGET75/UN=ER1200I".

(2) Submit RGET75 for computer processing using the command "SUBMIT,RGET75".

HIPLEX 24-HOUR RAINFALL DATA, MILES CITY, MONTANA 1975 717
THE GRID INTERVAL = .3000E 04 METERS. THE PLOTTED VALUES ARE SCALED BY .100E 01. PAGE 1.



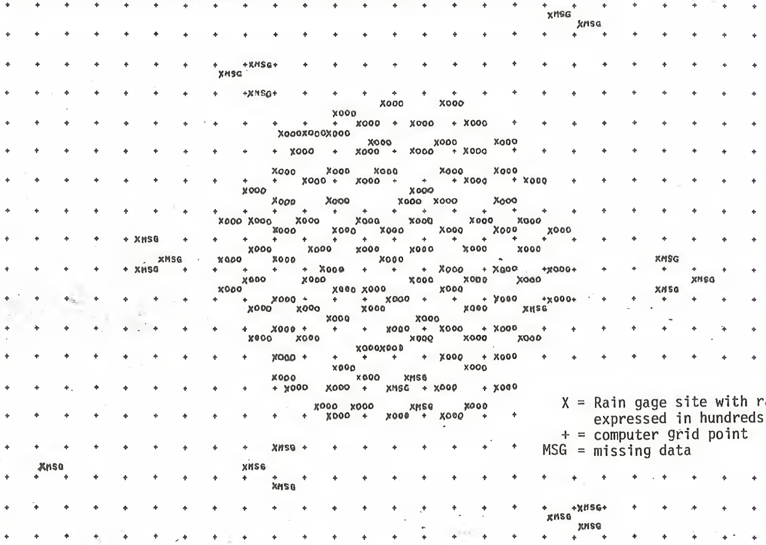
THE FOLLOWING VALUES WERE EITHER OFF THE MAP OR OVERPLOTTED.

N	XD	YD	I	J	VAL	REASON
56	.135E 02	-.450E 01	14.51	-3.50	046	OFF GRID
57	.135E 02	-.450E 01	14.51	-3.50	060	OFF GRID
58	.135E 02	-.450E 01	14.51	-3.50	035	OFF GRID
72	-.336E 02	.257E 02	.66	26.72	049	OFF GRID
73	-.106E 01	.271E 02	-.06	28.12	062	OFF GRID

X = Rain gage site with rainfall expressed in hundreds of an inch
+ = computer grid point
MSG = missing data

Figure II-7. Plot of daily rainfall - 1975

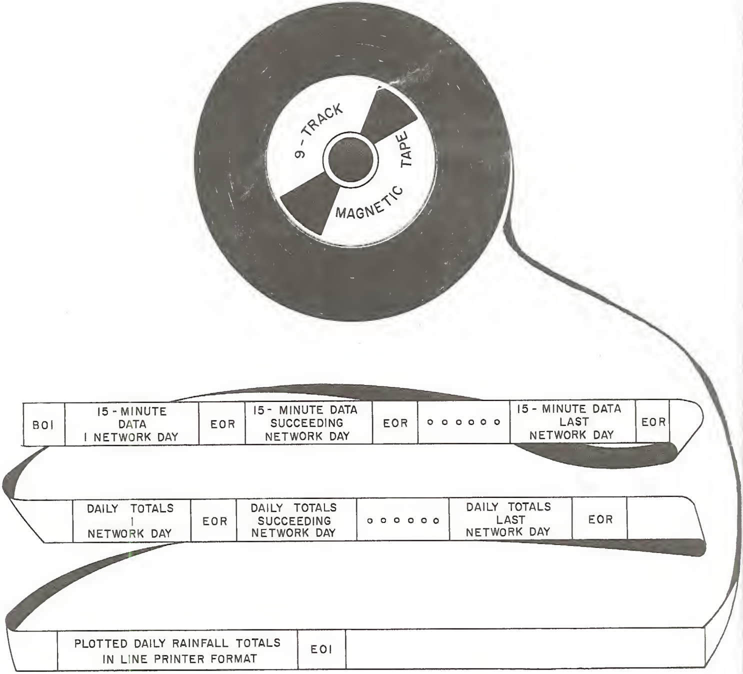
HIPLEX 12-HOUR RAINFALL DATA, MILES CITY, MONTANA, 12-24 MDT(0-6+18-24 GMT) 1976 7/7
THE GRID INTERVAL = .4000E 04 METERS. THE PLOTTED VALUES ARE SCALED BY .100E 01. PAGE 1.



THE FOLLOWING VALUES WERE EITHER OFF THE MAP OR OVERPLOTTED.

N	XO	YO	I	J	VAL	REASON
71	-.214E 00	.191E 02	.79	20.13	MSG	OFF GRID
129	.158E 02	.128E 01	16.75	2.28	MSG	OVER PRINTED

Figure II-8. Plot of daily rainfall - 1976



BOI - Beginning of Informotion

EOR - End of Record Mork

EOI - End of Information

Format of Rainfall Data on Magnetic Tape

Figure II-9

TABLE II-4

LISTING OF COMPUTER FILES-RGET75 AND RGET76

RGET76

```
00010 /JOB
00110 DATAGET.
00210 ACCOUNT,ER1200I.
00310 CHARGE,837100,8826.
00410 DEFINE,RAIN76/M=W.
00420 DEFINE,RANDY76/M=W.
00430 DEFINE,LNPRN76/M=W.
00610 REQUEST(TAPE1,NT,PO=W,F=I,D=1600,VSN=001155)
01510 COPYCR(TAPE1,RAIN76,111)
01520 COPYCR(TAPE1,RANDY76,111)
01530 COPYEI(TAPE1,LNPRN76)
01610 REWIND,RAIN76.
01620 REWIND,RANDY76.
01630 REWIND,LNPRN76.
01810 GOTO,DAYFILE.
01910 EXIT.
02010 DAYFILE,NTPUT.
02110 REPLACE,NTPUT.
02210 /EOF
```

RGET75

```
00010 /JOB
00060 DATAGET(P3)
00110 ACCOUNT,ER1200I.
00160 CHARGE,837100,8826.
00210 REQUEST(TAPE10,NT,PO=W,F=I,D=1600,VSN=000982)
00220 DEFINE,RAIN75/M=W.
00240 DEFINE,RANDY75/M=W.
00250 DEFINE,LNPRN75/M=W.
00260 COPYCR(TAPE10,RAIN75,183)
00360 COPYCR(TAPE10,RANDY75,183)
00410 COPYEI(TAPE10,LNPRN75)
00460 REWIND,RAIN75.
00560 REWIND,RANDY75.
00610 REWIND,LNPRN75.
00660 REWIND,TAPE10.
00760 GO TO, DAYFILE.
00810 EXIT.
00860 DAYFILE,DDUMP.
00910 REPLACE,DDUMP.
00960 /EOF
```

After a reasonable time, which varies from 15 min to 1 hour; three new computer data files will appear---RAIN75, RANDY75, and LNPRN75. RAIN75 contains 15-min rainfall totals for every rain gage during 1975. RANDY75 contains daily rainfall totals for every rain gage during 1975 and LNPRN75 contains plotted daily rainfall totals in lineprinter format.

On files RAIN75 and RANDY75, each network day (the rainfall data from the network for one day) is separated from other days by a physical EOR. To find the rainfall for a given day, one merely skips over the appropriate number of records and copies the desired information to an analysis file. For example, to analyze data from July 14, 1975 one first uses the computer command "SKIPR(RAIN75,75)". The Computer will skip the first 75 days of rainfall for 1975 (achieved by computing the number of days between April 30, 1975, the first day of the season, and July 14, 1975, the day of interest). One next uses the computer command "COPYBR(RAIN75,NEWNAME)". The computer will copy all rainfall data from July 14, 1975 to a new file named "NEWNAME". The 15-min rainfall totals from July 14, 1975 are now available for analysis.

A nearly identical procedure can be followed to obtain rainfall data for any desired day during 1976. Three notable differences are: RGET76 should be substituted for RGET75 in step 2 above; RAIN76 should be substituted wherever RAIN75 appears; and the first day of the 1976 field season is April 18.

If one is interested in daily rainfall totals rather than 15-min totals, file names RANDY75 or RANDY76 should be substituted wherever RAIN75 or RAIN76 appears in the procedure described. If a printed output of the 1975 or 1976 rainfall data is desired in plotted form the following computer commands should be used:

(1) COPYEI(LNPRN**,TAPE1)
(2) REWIND,TAPE1
(3) DISPOSE(TAPE1=PR/ID-67)

** either "75" or "76" depending on whether 1975 or 1976 rainfall data are desired.

These commands will produce plotted daily rainfall maps for either the 1975 or 1976 data.

In addition to the rainfall data generated by recording rain gages, two other precipitation data sources existed. Wedge or "Fence Post" rain gages were operated during the 1976 field season at each site to check the reliability of the Belfort and other rain gages. A hail pad was placed at each site to aid in detecting radar errors resulting from hail.

Data from both systems were collected once every seven days. All wedge rain gage information is stored at the Miles City HIPLEX site and will be made computer compatible before January 1, 1977. All hail data from the hail pads were subjectively classified as "light," "light to moderate," "moderate," or "heavy" by Bureau of Reclamation personnel. This information is available on request at the Miles City headquarters.

D) Analysis

Introduction. All 1975 and 1976 rainfall data were computerized by September 1, 1976. A preliminary analysis of the 1975 and 1976 rainfall data began at that time for the following purposes:

(1) Discover the percentage of total hourly rainfall episodes produced by various cloud types.

(2) Discover the distribution of percentage of amounts and episodes as a function of rainfall amounts for various cloud types.

This section discusses pertinent results from the analysis and the procedures used to obtain them.

Data Base. Two data sources were used in the analysis; network rainfall data from Miles City, Montana, during May-July of 1975 and 1976 and cloud photography data from a time-lapse camera located at Miles City.

During both years rainfall data were taken from Belfort recording rain gages (73 in 1975 and 109 in 1976) each with the orifice at 1 m above ground level. The data were 15-min rainfall totals precise within ± .02 in and ± 1 min per day, as described earlier.

Cloud photography data were taken from a time-lapse Super-8mm camera facing the rain gage network. These data allowed an observer to classify clouds as they passed over the rain gages.

Procedures. Two computer manipulations were performed on the rainfall data to prepare it for analysis. First, all 15-min rainfall totals were converted to hourly totals. Hourly rainfall totals were chosen for analysis because they appeared more typical of summertime storm durations at the rain gage sites. Second, all hourly rainfall totals were stratified and totaled in 0.1 in increments. The resultant output consisted of daily summaries of the number of hourly rainfall episodes whose rainfall totals fell within each 0.1 in increment between 0-2.0 in. A rainfall episode is defined as the occurrence of measurable precipitation at a rain gage during the preceeding hour. For example, a shower which produces rainfall at three gage sites during an hour will create three rainfall episodes.

Cloud photography data were used to classify the predominent cloud type occurring during each storm period during 1975 and 1976.

Only photographic data filmed over the rain gage network were used in the classification. Because of the limited field of view, errors in the classification are possible. That is, a mesoscale cumulonimbus system may wrongly be classified as overcast or stratus because only a uniform cloud base can be seen in the photographs.

In 1975 the following classifications were used:

(1) overcast - refers to stratus clouds with a sky coverage greater than 90 percent

(2) cumulus - refers to cumulo-nimbus, cumulus congestus or cumulus clouds

(3) mid-level - refers to alto-cumulus, alto-stratus or cirrus densus clouds

In 1976 the following classifications were used:

(1) alto-cumulus (ACu)

(2) cumulo-nimbus (Cb)

(3) cumulus (Cu)

(4) stratus (St)

(5) camera off - refers to rainfall episodes which occurred between 0200-0800 GMT when the camera was not operating.

During 1975, Dr. Ed Holroyd classified cloud types from the photographic record. During 1976, Joey Boatman classified them. Although all cloud classifications were made subjectively, the significance of the distinction between "Cu" and "Cb" during 1976 needs further clarification. Cumulus clouds which either developed or moved over the rain gage network were classified as Cu if they lacked a cirrus anvil during their passage. Otherwise they were classified as Cb.

As part of purpose 1, the rainfall episodes occurring during each day were classified as belonging to a particular cloud type (determined from cloud photography data). Then, the distribution of percent of total episodes as a function of cloud type for May, June, and July of the two years was determined.

As a part of purpose 2, graphs (Figs. II-10 and II-11) were plotted to determine the percent total rainfall episodes and amounts for each cloud type at 0.1 in intervals between 0-2.0 in. Since it was suspected that these distributions would have an exponential decay rate from lower to higher rainfall increments, a semi-log scale was used for graphing purposes.

Results. Following the procedures outlined, three histograms of percent of rainfall episodes stratified by cloud type were produced for 1975 (Fig II-10 A-C). During May, 1975, 57 percent of the episodes were from "overcast" type clouds (typically stratiform in nature) while 43 percent were from "cumulus" type clouds. However, during June and July, 1975, 88 and 98 percent of the episodes eminated from cumulus type clouds, respectively.

Clearly cumulus type clouds appeared responsible for more episodes than did either overcast or mid-level. To emphasize this, another histogram of percent episodes stratified by cloud type for the period May-July, 1975, was constructed (Fig II-10 D). Cumulus type clouds produced nearly 80 percent of the rainfall episodes observed.

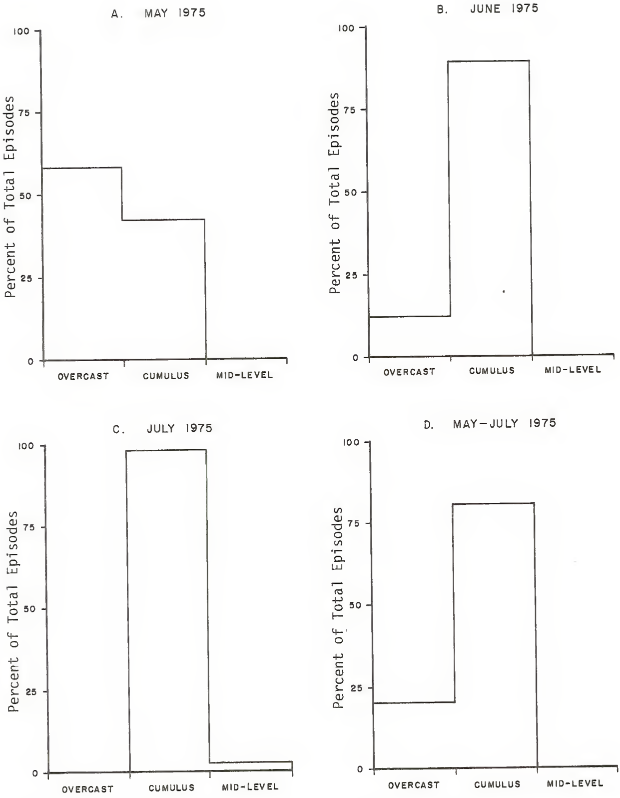


Figure II-10. Percent of total hourly episodes observed from three cloud types during A-May; B-June; C-July; and D-May-July, 1975.

Figure II-10 D also reveals that mid-level type clouds produced less than 1 percent of the rainfall episodes observed. This cloud type was seen to emit rainfall which seldom reached the ground in significant amounts (Holroyd, 1976).

For comparison, a similar analysis was performed on the 1976 rainfall data. Three histograms of percent rainfall episodes stratified by cloud types were produced for 1976 (Fig. II-11 A-C).

During May, 1976, the majority of rainfall episodes were from ACu (34%) and St (35%) type clouds while Cb and Cu accounted for 18 and 7 percent of the monthly total, respectively. Whereas, during June, 1976 the majority of rainfall episodes were of Cb (61%) or Cu (33%) origin. Moreover, Cb clouds increased in relative frequency and completely dominated in July, 1976, with 84 percent of the total episodes.

Again, the Cb and Cu categories produced more rainfall episodes than did the other classification types. The histogram of episodes stratified by cloud type for the period May-July, 1976, showed that cumulo-nimbus clouds produced 59 percent of the total rainfall episodes with cumulus-congestus clouds accounting for 17 percent (Fig.II-11 D). If Cb and Cu episodes are grouped into one category, as in 1975, it is evident that cumulus cloud systems were again responsible for most of the rainfall episodes (76%).

A comparison of episodes from Cb and Cu systems for 1976 is also informative. Throughout the May-July period Cb systems were responsible for significantly more rainfall episodes than were Cu systems.

Finally, during 1976, ACu systems were responsible for only 12 percent of the May-July episodes. This percentage is much higher than the 1976 total of under 1 percent, but still represents a small portion of the total.

The second purpose of the analysis was to discover the rainfall distribution, if any, which is representative of the cumulus, mid-level and overcast cloud types. To accomplish this, episodes were stratified into 0.1 in increments and totaled for each day. Every storm was classified by predominant cloud type and the rainfall data for that period was assumed to have originated from it. Finally the total rainfall which occurred during each day was computed and the fraction of that total which fell within each 0.1 in increment was calculated.

Figures II-12 and II-13 present the results of this analysis for May-July, 1975. Figure II-12 represents the percent of total rainfall amount by cloud type which fell within each 0.1 in increment and Fig. II-13 represents the percentage of the total number of rainfall episodes by cloud type which fell within each 0.1 in increment. A substantial number of rainfall episodes, except in the case of mid-level type clouds, is included in the analysis.

An exponential equation was fit to the points representing each cloud type, using a least squares technique. The empirical equations are given opposite the cloud type represented. In addition, a statistical test of their representativeness was made. The probability (from 0-1) that the equations actually represent the plotted points is given following each equation.

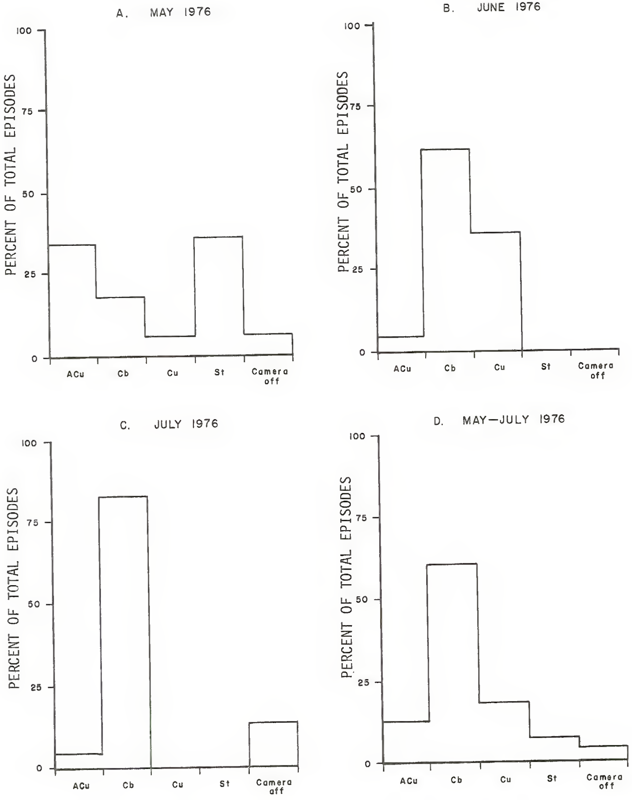


Figure II-11. Percent of total hourly episodes observed from four cloud types during A-May; B-June; C-July; and D-May-July, 1976. Camera off - 0200-0800 GMT.

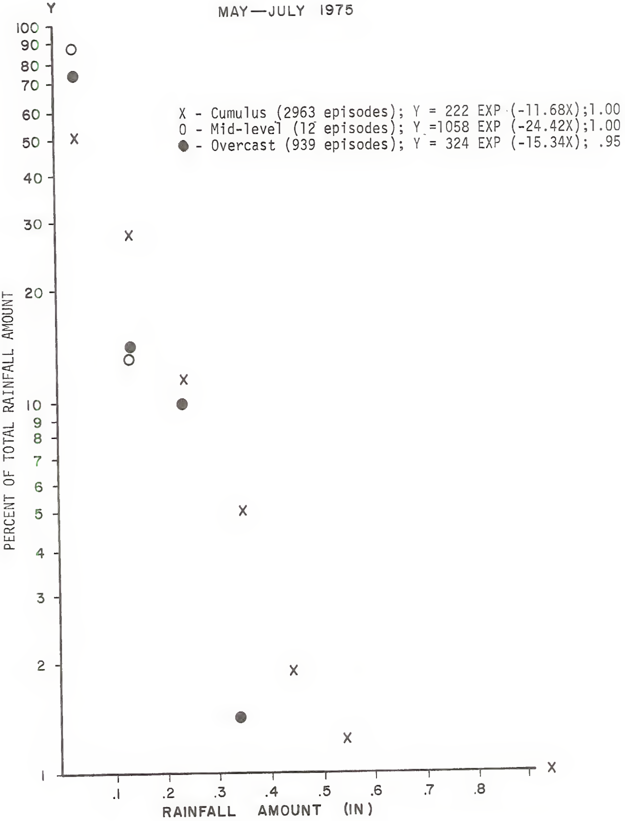


Figure II-12. Percent of total hourly rainfall amounts vs. rainfall amount for indicated cloud types.

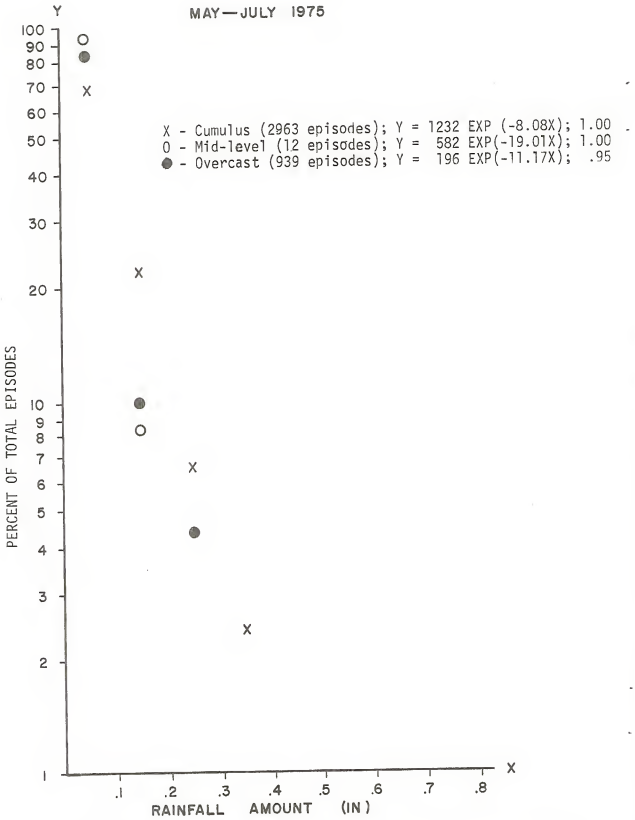


Figure II-13. Percent of total hourly rainfall episodes vs. rainfall amount for indicated cloud types.

Three features of these graphs should be noted:

(1) An inverse exponential function describes the rainfall distribution for each cloud type.

(2) The cumulus distribution decays more slowly than do those of the other cloud types. In a physical sense, this indicates that cumulus type clouds produce proportionately higher hourly rainfall amounts than do the other cloud types.

(3) More than 50 percent of the number of hourly episodes and of the total hourly rainfall amounts in each cloud classification occurred within the interval of 0-0.1 in.

As a continuation of this analysis all rainfall data from May-July, 1976, were processed in the same manner (Figs. II-14 and II-15). Again, a substantial number of rainfall episodes were included in the analysis. The cloud classifications used in 1975 were repeated for the 1976 data by equating the cloud classifications of 1976 to those of 1975. The following classes were made equivalent:

Cumulus equivalent to Cb or Cu
Mid-level equivalent to ACu
Overcast equivalent to St

The three features discussed earlier again emerge as important. The data from each cloud type are exponentially distributed, and decrease in percent total at higher rainfall increments. More than 50 percent of the number of episodes and of the total rainfall amount in each cloud classification occurred within the interval 0-0.1 in.

Discussion. An analysis was performed using 1975 and 1976 surface rainfall and cloud photography data for two purposes:

1) to discover the percentage of total hourly rainfall episodes produced by various cloud types; and

2) to discover the distribution of percentage of amounts and episodes as a function of rainfall amount for various cloud types.

As a part of purpose 1 three significant results were obtained.

1) Cumulus type clouds produced a vast majority of the rainfall episodes during the months of June and July of 1975 and 1976. During May of both years rain from stratiform and alto-cumulus clouds predominated. Overall, cumulus type clouds were the most frequent rain producers in both years.

2) Alto-cumulus or mid-level type clouds produced virtually no rainfall episodes during 1975 and only 12 percent of the May-July rainfall episodes during 1976. All of the 1976 rainfall episodes produced by alto-cumulus clouds occurred during May.

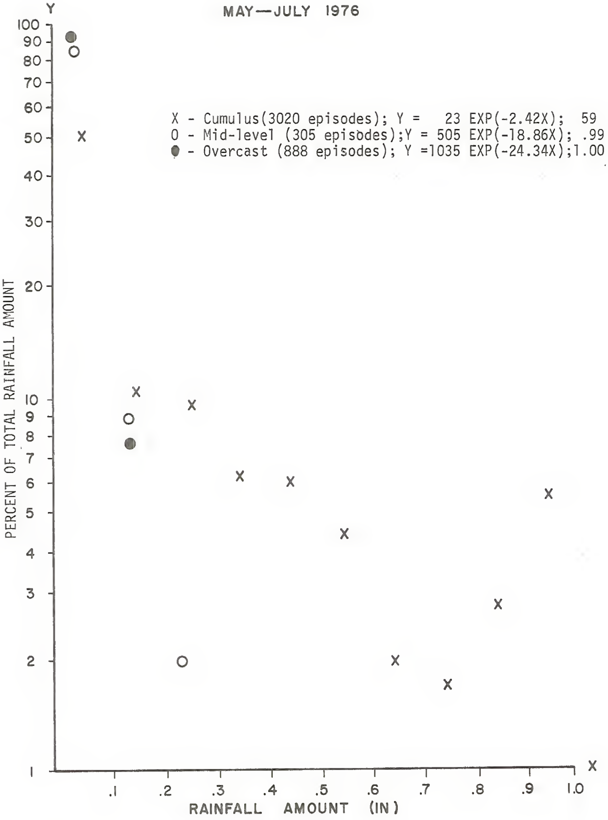


Figure II-14. Percent of total hourly rainfall amounts vs. rainfall amount for indicated cloud types.

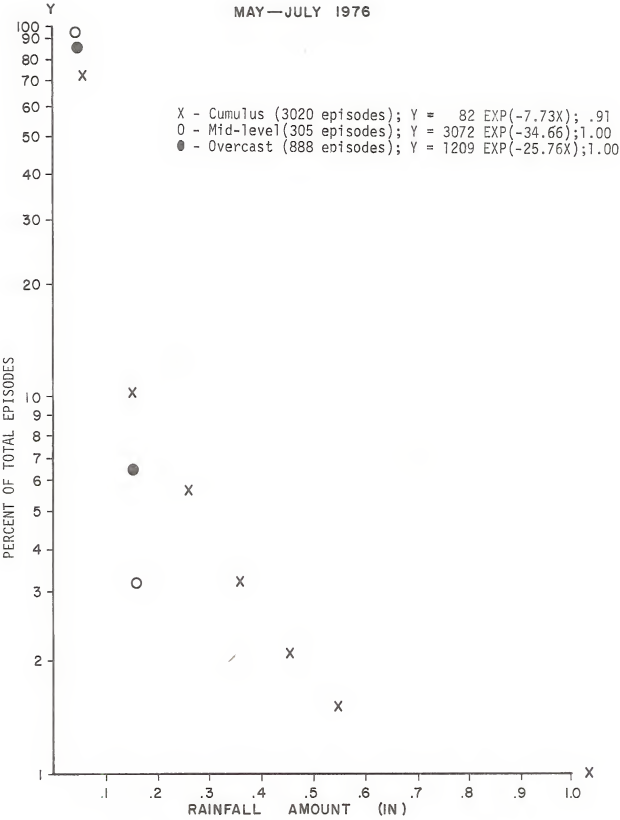


Figure II-15. Percent of total hourly rainfall episodes vs. rainfall amount for indicated cloud types.

3) A majority of the cumulus type rainfall episodes of 1976 were produced by cumulo-nimbus cloud systems (78% for May-July).

As a part of purpose 2, three significant results were obtained.

1) Percentage of both total hourly rainfall amount and number of rainfall episodes is an inverse exponential function of the rainfall increment. This means that the observed hourly rainfall amounts and episodes decrease exponentially toward higher rainfall values.

2) The exponential decay rate of the cumulus type distribution is slower than those of either the mid-level or overcast . Cumulus type clouds produced proportionately higher hourly rainfall amounts than did mid-level or overcast type clouds.

3) More than 50 percent of the rainfall episodes produced in each cloud classification occurred within the interval of 0.0-0.1 in.

In arriving at these results two important assumptions were made. First, it was assumed that an hour was typical of summertime storm durations. Second, it was assumed that each storm period had a predominant cloud type responsible for the rainfall on that day.

E) Recommendations

The data management system as developed thus far has worked well in providing reliable rainfall data in a short period of time. This system should continue to function well in succeeding years. One improvement was the addition of a card punch machine and a punch card reader to the Miles City facility. This allows codification of rainfall data on punch cards and entrance of this information into the computer, thus speeding the entry of coded rainfall data to the computer and providing an easily reloadable source of coded rainfall data for the remote possibility of information loss.

Radar Operation

Herb Craig, Joey Boatman and Marty Lynam

This section describes Montana's role in the collection and analysis of radar data, as well as the maintenance and daily operation of the Skywater SWR-75 radar system. More detailed descriptions of radar calibration and data collection procedures are found in the 1976 HIPLEX Operations Plan. Radar data reduction and storage techniques used during 1976 are outlined by Schroeder and Klazura (1976).

A) Training. The electronic technician (H. Craig) participated in two training exercises during 1976. An intensive 40-hour course explaining the digital portion of the SWR-75 radar was held in Denver, Colorado. Extensive training was also received during two radar modifications at the Miles City research site.

These modifications to the SWR-75 radar came in two areas. First, "blue sky elimination" equipment was installed to suppress all power returned below a predetermined threshold. This significantly reduced the number of magnetic tapes of radar data. Second, a more sophisticated IFF (aircraft identification) control unit was installed, allowing aircraft locations to be recorded on magnetic tape and displayed at the operator's console.

Due to the modifications, several power supplies (± 5 volt) were upgraded with larger and better regulated units.

B) Maintenance. Before starting the 1976 field season, a complete inspection of the SWR-75 radar was performed. During the inspection, the feedhorn assembly (responsible for guiding and transmitting pulses of radar frequency energy) was found to be damaged. The damage was caused by drag against a lightning rod ground cable. The assembly was removed and returned to the manufacturer who tested the damaged horn and indicated that it would not significantly change the radar system gain. The feedhorn was then repaired and re-installed. It was used until arcing was noticed, apparently due to the repair. A new assembly, therefore, had to be installed during the mid-season calibration.

Several nuisance problems arose during the field season. A power supply (± 5 volt) for the Digital Video Integrator Processor failed. Necessary repairs were completed with available parts. A 115 volt A.C. relay in the same power supply also failed. Again repairs were completed with available parts. A power outage caused the malfunction of a compressor in the main air conditioner. Two window air conditioners were installed in the radar van while a new compressor was ordered. Delivery of a new compressor and repair of the malfunctioning air conditioner was completed within seven days.

The preventative maintenance program established during the 1976 field season exposed most of the problems in time for correction before the beginning of each operational day (1730 GMT). During the 1976 field season the SWR-75 radar operated 1150 hours with an efficiency of 99.1 percent; the unit was "down" for repair only 0.99 percent of all operational hours.

C) Calibration. The radar was calibrated against balloon-suspended spheres at the beginning of the season and during mid-season according to the procedures found in the 1976 HIPLEX Operations Plan. As well, daily electronic calibrations were made using the procedures described in that plan.

D) Data Reduction. One of the major purposes of the Skywater digital weather radar (SWR-75) during 1976 was to obtain data on the structure, life history and spatial distribution of convective cells in the local experimental area (Ackerman, 1975). To obtain these data it was necessary to reduce the raw data tapes produced by the SWR-75 to a form more easily analyzed by researchers. This reduction requires, at one point in the data flow, an analyst to identify cells, measure their location and transcribe this information into a form compatible with the Bureau of Reclamation's Cyber 74-28 computer (Schroeder, Brady and Brueni, 1976).

In early September DNRC began this data reduction at the Miles City offices. The purpose for DNRC's involvement was to further expose the staff to the format, analysis and disposition of the SWR-75 data.

What follows is a brief description of the SWR-75 data reduction process. A status report is included showing the progress made in this activity as of this writing.

Radar Data Flow. Data consisting of azimuth, range, and elevation of echoes, plus general information regarding the date, time, and radar system configuration at the time of the scan are recorded on 9-track, 800 bpi, computer compatible magnetic tape (Schroeder, Brueni and Klazura, 1976). Each tape may contain up to 13,000 records, representing from 1 to 12 hours of radar data depending on the number of radials that contain echo information.

These tapes are mailed to the Bureau of Reclamation's computer facility in Denver for partial processing (steps 1, 2 and 3 of Fig. II-16). Printouts of the composite-B scan generated by computer program RECORDL (see Fig. II-17) are then mailed back to the Miles City office for analysis (steps 4, 5 and 6 of Fig. II-16).

At the Miles City office data clerks identify the cells (Fig. II-17), measure their position and transcribe this information onto FORTRAN coding sheets. These completed sheets are then taken to a local firm which has contracted to punch 80 column computer cards from the sheets.

After punching, the cards are read using a remote batch facility located at the Miles City HIPLEX office. A computer file is being built to contain the cell location and other identification data. This file is then being checked for syntax and other errors (steps 5 and 6, of Fig. II-16) and a corrected file produced. Once this task has been accomplished a series of reports can be produced for use by researchers.

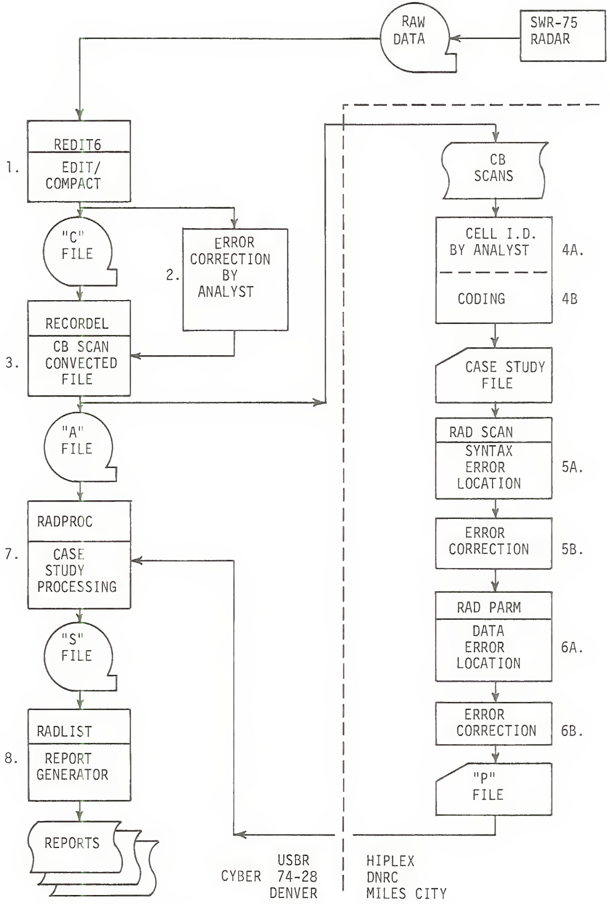


Figure II-16. Procedure for Processing HIPLEX Radar Data

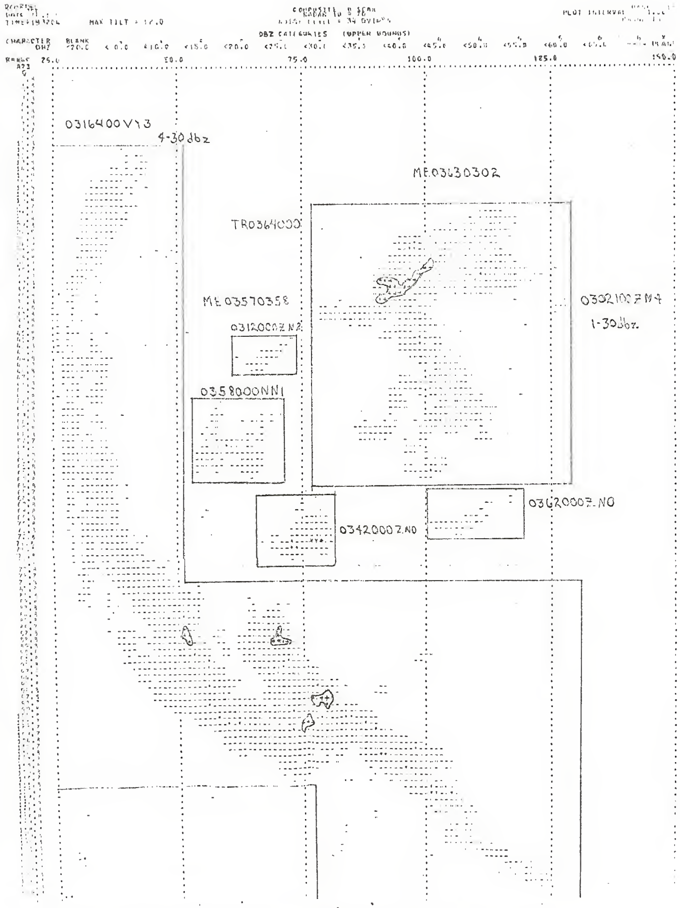


Figure II-17. Printout of composite-B scan with cells boxed (Reduced ½ scale)

Status of Radar Reduction. As of this writing (mid Oct., 1976) DNRC's portion of the radar project is 65 percent completed. Using the figures in Table II-5 as a guide, the project should be completed on schedule by mid-December, 1976.

TABLE II-5

STATUS OF RADAR DATA REDUCTION PROJECT
October 15, 1976

Task	Percent of 246 Radat Data Tapes Completed
Cell identification	75%
Data coding	60%
Card punching	16%
File correcting*	?
Files completed*	?

*Software development is the responsibility of the DAWRM staff

CHAPTER III

AGRO-ECOLOGICAL STUDIES

A Comparison of Native Range Species in Permanent Plots After an Extended Period of Above Average Precipitation

Preliminary Report - October 1976

John Newbauer, Larry White and Ann Losinski

Introduction

Perry (1976) commented that changes in rainfall will generally have a corresponding change in species composition of grasslands. With below normal rainfall for extended periods, a reduction is expected in basal cover (Anderson, 1973, Reed, and Person 1961) height, forage yield, and seed production (Coupland, 1958) with a corresponding decrease in the density of blue grama (Bouteloua gracilis), western wheatgrass (Agropyron smithii), and needle-andthread (Stipa comata). In contrast, sandburg bluegrass (Poa secunda) is expected to increase (Ellison and Woolfolk 1937; Norem, 1940;and Reed and Peterson, 1961).

During extended periods of above average rainfall the characteristics of range vegetation may shift toward a more mesic type in which the midgrasses, (Stipa, Agropyron), play the dominant role (Coupland, 1958).

The timing of precipitation is important in rangeland production. Smoliak (1956) showed that May and June rainfall is important to current seasons forage production in Alberta. Whitman (1972) found that previous September and October precipitation and April-July rainfall of the current season favor forage production in North Dakota. Rogler and Hass (1947) also reported a significant correlation between fall soil moisture content and native forage production the following season in North Dakota. They found that above average rainfall in April-July increases yield 70 percent of the time, while below average rainfall in these months decreases yield 100 percent of the time.

Permanent plots on native range offer the potential for monitoring changes in community composition due to increases or decreases in rainfall over extended periods. Since the natural fluctuation in rainfall is greater than that expected from summer cloud seeding, the five permanent plots reported herein, analyzed first in 1936, provide an excellent opportunity to examine changes which occurred due to a higher rainfall regime. Specifically, since most of these plots experienced above normal growing season rainfall during 10 of the last 13 years.

Only two known publications document species change resulting from several years of above-average rainfall. Coupland (1959) used a point-transect method

to determine the basal cover of principal species after twenty years of favorable growing conditions in Saskatchewan, Canada. Reed and Peterson (1961), (while conducting a grazing study), commented on vegetative changes between 1932 and 1945 near Miles City, MT. This study, therefore, was initiated to determine the effects of above average rainfall on rangeland composition in the Northern High Plains of Montana between 1963 and 1976.

General Description of Soils. The study plots are located in the northern rolling High Plains. The landscapes are rolling to steep uplands located stratigraphically in the tertiary aged Fort Union formation. The formation consists of loam and clay shales with occasional lenticular concretions of impure limestone and imbedded sandstone. Thin coal beds are common.

Grazing Pressure. Grazing records for the period 1950 to 1976 were obtained from the Bureau of Land Management and the Prairie County Conservation District. These records (Table III-1) reflect the variability of grazing practices and grazing pressure between sites. Grazing use was classified as: no use; slight; moderate; full; heavy use; extreme; and destructive.

TABLE III-1

GRAZING PRESSURE ON NATIVE RANGE SITES

	Grazing Pressure		
Site #	1950 to 1963	1963 to 1976	Season of Use
18	slight to moderate	slight to moderate	1949 to 1959 - April 1 to November 30 1959 to 1964 - April 1 to June 30 and fall 1964 to 1976 - May 1 to May 30 September 1 to October 15
19	full	full to heavy	variable from year to year
20	light to moderate	light to moderate	April 1 to November 30. No use in 1971-72
21	moderate to full	moderate to full	1950 to 1959 - April 1 to November 30 1959 to 1976 - April 1 to October 30
22	heavy	heavy	1950 to 1976 - April 1 to October 30

Materials and Methods

Permanent plots, representative of native range of the area, were remapped in 1963 and 1976 using the same methods employed for the readings in 1936 and 1938. The methodology for determining species composition and basal area were the same in 1963 and 1976. Larry White, who analyzed these plots in 1963,[1] was

1. At that time Range Conservationist, Bureau of Land Management, Miles City, MT. Presently Range Scientist, Agricultural Research Service, Northern Plains Soil and Water Research Center, Sidney, MT.

also involved in the 1976 study.

The plots were located in five sites near Mildred and Terry, Montana (Fig. II-1). Each site was divided into five plots (0.30 x 1.52 m; 12 x 70 in) and each plot was distinctly marked for relocation. However, a few of the original plots were lost by, for example, the location of a road.

A frame, (30 x 152 cm.; 12 x 60 in) which was strung with wires forming a 5.13 cm (2 in) grid, was used to read the plots. Plots were mapped beginning June 8, 1976, and completed June 11, 1976 (with the exception of site #21 which was mapped on June 18). Readings at this time of year provided the best opportunity for recording the presence of annuals, as well as warm and cool season perennials.

The basal area was mapped by species on graph paper at 1/2 scale as illustrated in Figs. III-2 and III-3. Locations of ant hills, cow chips and other material occupying area within the frame were mapped and recorded.

The graphed plots were planimetered, using a compensating polar planimeter from Weather Measure Corporation, to determine the area occupied by each species. Each area was traced at least twice. Acceptable readings were within 0.07 cm^2 (0.01 in^2) of each other, but 0.10 cm^2 (0.03 in^2) variance was allowed for readings larger than 6.45 cm^2 (1 in^2). Percent composition of each species will be determined from the total basal area.

Precipitation and temperature records from a National Weather Service Cooperative station located at Mildred were analyzed and compared to vegetative changes at all sites.

Results

The results herein are preliminary; data reduction and analyses are not yet complete. A complete quantification of changes in species composition by basal area is planned.

The growing season precipitation (April-September) for the 13 year study period between 1963 and 1975 averaged significantly higher at 29.1 cm ($P < 0.05$) compared to either that of the previous 35 year average (1928-1962) of 24.5 cm or that of the previous 13 year average (1950-1962) of 23.5 cm. Specifically, the growing season precipitation was higher 10 of 13 years of the study period compared to the previous 35 year average (Fig. III-4).

In addition, the annual precipitation for the study period averaged higher at 35.7 cm compared to an average of 31.3 cm for the 1928-1962 period.

Monthly precipitation totals of the 13-year study period averaged higher in March, April, June, September, and October compared to that of the previous 13 years (1950-1962) (Fig. III-5). In contrast, the earlier period had slightly higher precipitation averages during May, July, and August. June rains had the highest difference between the two periods averaging 3.3 cm higher during the study period.

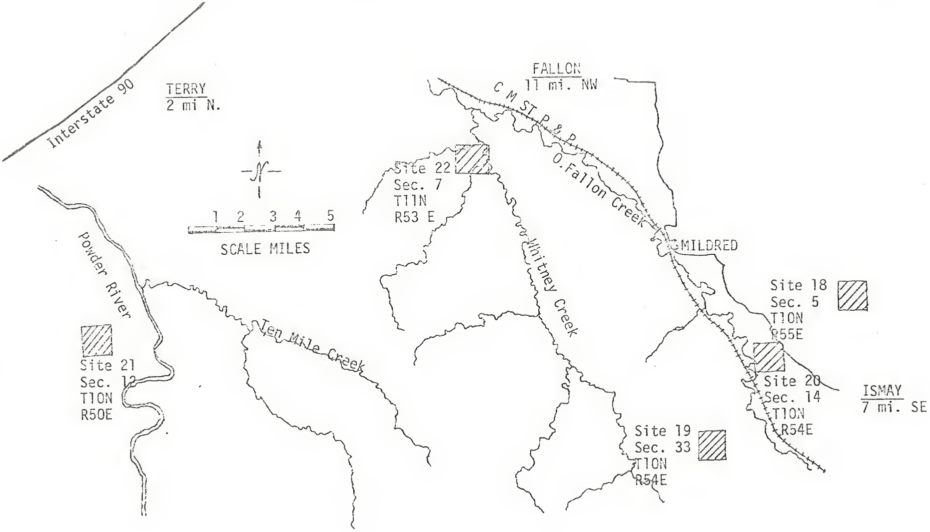


Figure III-1. Location of permanent plots.

Quadrant #22 Plot #4 Sheet #A
Location: 7 chains S 81½° W of plot #3
Exposure: level
Date: 7-26-63

Legend:
B=Bogr=Bouteloua gracilis
✓=Agropyron smithii
Bu=Buchloe dactyloides
Sp=Spco=Sphaeralcea coccinea
Pose=Poa secunda
Ce=Carex eleocharis
Arca=Artemisia cana

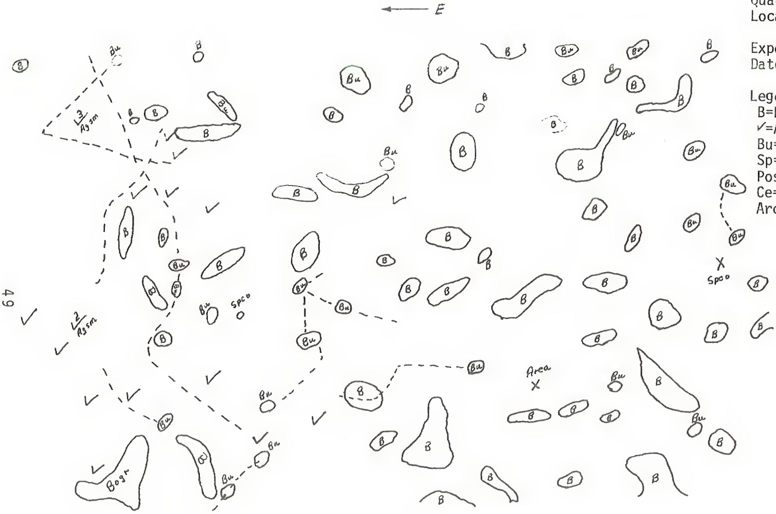


Figure III-2. Basal area of site 22 - plot #4, sheet A in 1963. (Reduced)

Quadrant #22 Plot #4 Sheet #A
Location: 7 chains S $81\frac{1}{2}^{0}$ W of plot #3
Exposure: level
Date: 6-11-76

Legend:
B=Bogr=Bouteloua gracilis
Ag sm=Agropyron smithii
Bu=Buchloe dactyloides
Sp=Spco=Sphaeralcea coccinea
Pose=Poa secunda
Ce=Carex eleocharis
Arca=Artemisia cana

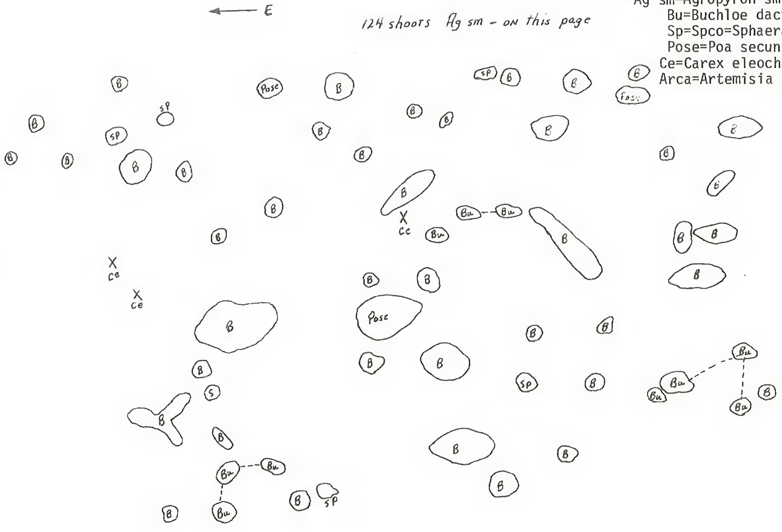


Figure III-3. Basal area of site 22 - plot #4, sheet A in 1976. (Reduced)

GROWING SEASON PRECIPITATION - MILDRED, MT

(April - September)

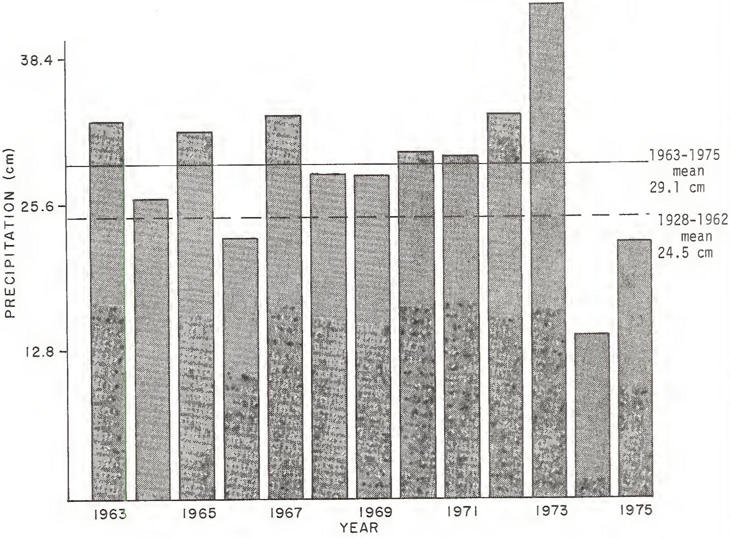


Figure III-4

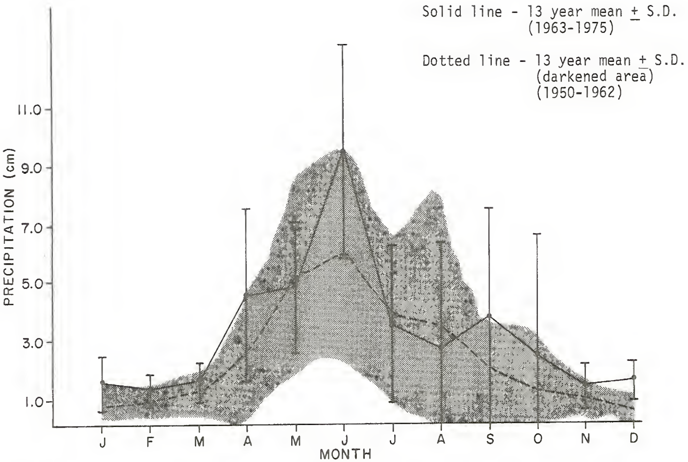


Figure III-5. Average monthly precipitation - Mildred, Montana

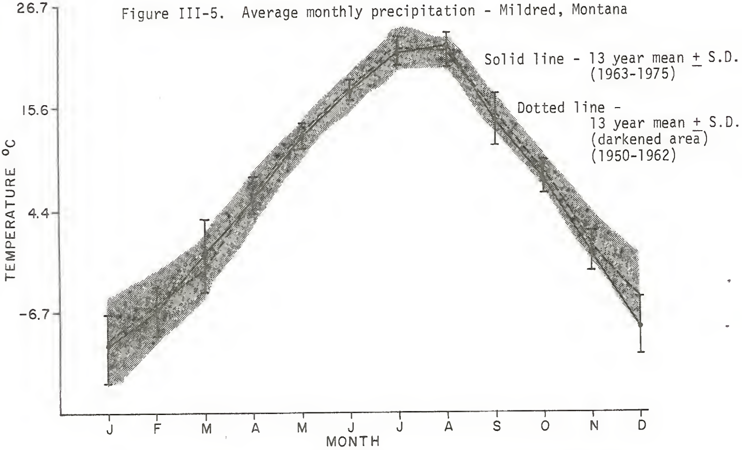


Figure III-6. Average monthly temperature - Mildred, Montana

The average April-September growing season temperature for the two 13-year periods (1950-1962 and 1963-1975) was not significantly different ($P > 0.01$) (Fig. III-6). The small differences in monthly mean temperatures of the two periods can be seen in Fig. III-6, consequently, temperature was unlikely to have been a significant factor in causing vegetative changes.

The data showed an increase in basal area at all sites. The mean basal area increased by 170 percent and ranged between 130-250 percent. The larger increase at sites 18 and 19 (250 and 180 percent respectively) may be due to a combination of additional rainfall and a change in grazing practices (refer to Table III-1). All remaining sites showed an increase in basal area of 130 to 150 percent with no substantial change in grazing practices. This increase appears to be largely due to an increase in basal area of western wheatgrass, prairie junegrass (Koeleria cristata), and needleandthread, along with warm season grasses such as blue grama, red threeawn (Aristida longiseta), and little bluestem (Schizachyrium scoparium). For example, Figs. III-2 and III-3 show that western wheatgrass increased markedly from 19 shoots in 1963 to 124 shoots in 1976 and that buffalo grass (Buchloe dactyloides) decreased. Western wheatgrass and prairie junegrass showed an increase at four of five sites while needleandthread increased at all sites (Table III-2). The increase of cool season grasses is probably related to the increase in spring and fall precipitation over the past 13 years (refer to Fig. III-5) (Hyder, 1975; Perry, 1976). The warm season grasses showed an increase at three sites, possibly due to late summer and fall precipitation of the previous years (Hyder 1975; Perry, 1976).

Forbs, such as yellow salsify (Tragopogon dubius), scarlet globemallow (Sphaeralcia coccinea), rush skeletonplant (Lygodesmia juncea), and prairie coneflower (Ratibida columnifera) showed an increase over the 1963 recordings (Table III-2). Fringed sagewort (Artemisia frigida), a half shrub, also showed an increase at three of the five sites.

Discussion

Five sites, consisting of 23 plots, were mapped for basal area by species and are being compared to maps of the same plots prepared in 1963 (refer to Table III-2). The increase or decrease in percent composition by basal area can probably be largely attributed to 10 of 13 years of relatively wet weather rather than temperature differences although changes in grazing practices may have also been a factor at two sites. The data showed an increase in basal area at all sites studied. The mean basal area increased by 170 percent ranging from 130 to 250 percent. The two sites with the largest increase experienced changes in grazing practices. The remaining sites showed less increase in basal area with no substantial change in grazing practices. A preliminary analysis suggests that the cool season grasses (western wheatgrass, needleandthread, and prairie junegrass) have increased with increased rainfall. Warm season grasses of red threeawn, blue grama, and little bluestem have also increased.

Forbs and shrubs which have increased since 1963 include yellow salsify, scarlet globemallow, prairie coneflower, and fringed sagewort.

CHANGES IN SPECIES COMPOSITION BY BASAL AREA

Table III-2

Scientific Name	Common Name	Status in 1976* new	+	-	without
Grasses					
Agropyron smithii	western wheatgrass	1	3	1	0
Agropyron spicatum	bluebunch wheatgrass	0	1	1	3
Aristida longiseta	red threeawn	2	1	0	2
Bouteloua curtipendula	sideoats grama	0	1	0	4
Bouteloua gracilis	blue grama	0	3	2	0
Bromus japonicus	Japanese brome	1	0	0	4
Buchloe dactyloides	buffalo grass	1	1	1	2
Carex eleocharis	needleleaf sedge	3	0	2	0
Carex filifolia	threadleaf sedge	0	3	1	3
Carex heliophila	sun sedge	1	0	0	4
Calamovilfa longifolia	prairie sandreed	0	1	0	4
Calamagrostic montanensis	plains reedgrass	2	0	0	3
Festuca octoflora	six weeks fescue	2	0	0	3
Koeleria cristata	prairie junegrass	2	2	0	1
Muhlenbergia cuspidata	stoney hills muhly	0	1	0	4
Poa secunda	sandberg bluegrass	1	1	1	2
Schizachyrium scoparium	little bluestem	2	0	0	3
Sporobolus cryptandrus	sand dropseed	1	0	0	4
Stipa comata	needleandthread	0	5	0	0
Stipa viridula	green needlegrass	0	0	1	4
Shrubs and half shrubs					
Artemisia cana	silver sagebrush	0	0	1	4
Artemisia frigida	fringed sagewort	1	2	1	1
Ceratoides lanata	common winterfat	0	0	1	4
Gutierrezia sarothrae	broom snakeweed	1	0	1	3
Yucca glauca	small soap weed	2	0	0	3
Forbs					
Arenaria congesta	ballhead sandwort	0	0	1	4
Cirsium undulatum	waveyleaf thistle	0	0	1	4
Echinacea pallida	pale echinacea	0	2	0	3
Lappula redowskii	blue bur stockseed	2	0	0	3
Liatris punctata	dotted gayfeather	2	0	0	3
Lygodesmia juncea	rush skeletonplant	1	2	0	2
Mammillaria vivipara	purple mammillaria	1	1	0	3
Melilotus officinalis	yellow sweetclover	1	0	0	4
Opuntia polycantha	plains pricklypear	1	0	1	3
Petalostemon purpureum	purple prairieclover	1	0	0	4
Phlox hoodii	Hoods phlox	0	2	1	2
Plantago purshii	wooly plantian	2	0	1	2
Polygala alba	white polygala	1	0	0	4
Psoralea agrophylla	silverleaf scurfpea	1	0	0	4
Solidago missouriensis	Missouri goldenrod	1	0	0	4
Ratibida columnifera	prairie coneflower	2	0	0	3
Sphaeralcea coccinea	scarlet globemallow	2	1	2	0
Taraxacum officinale	common dandelion	1	0	0	4
Tragopogon dubius	yellow salsify	3	0	0	2

* new = site(s) in which the species are present in 1976 but not in 1963
+ = increase in % composition by basal area
- = decrease in % composition by basal area
without = site(s) in which the species did not occur

Canopy-Water-Holding-Capacity Vs Throughfall-Stemflow in Barley

Preliminary Report: October, 1976

Tad Weaver and John Newbauer

INTRODUCTION

Water falling into vegetation, whether rainfall or irrigation water, may be intercepted by the vegetation or may fall directly through the canopy (e.g. Horton 1919). That which falls directly to the soil (throughfall) is available for plant use if it doesn't run off, percolate below the rooting zone, or evaporate directly from the soil surface. Intercepted water may run down the stem (stem flow), may be absorbed by the plant, or may evaporate directly from the leaf surface.

The object of this study was to determine how the water from a 8mm (0.3 in) shower is partitioned (described above) in cultivated barley fields. Canopy catch was emphasized because most water caught in the canopy probably evaporates within a few hours following the shower.

METHODS AND RESULTS

Plots and Treatment. The partitioning of a 8 mm rain shower was contrasted in barley plots with 15, 30, and 45 cm (6, 12, and 18 in) rows and at four developmental stages: 4 leaf, 6 leaf, flowering, and ripening. The plots were located two miles south of Bozeman in a barley field growing on Bozeman silt loam soil. (The cooperation of the Goldenstein family is gratefully acknowledged.)

Eight mm rainshowers were simulated with a pump and rotating rain-bird sprinklers placed 1.4 m above the ground on posts (Figure III-7). Drop sizes were 1 to 3 mm, which approximate drop sizes expected from thundershowers. Water falling into the experimental area was measured at two points approximately 3 m from the posts, by pairs of level wedge-type rain gages, mouths of which were at the top of the vegetational canopy. Water reaching the ground was measured in the vicinity of the rain gages.

Figure III-7. Location of wedge gages, rain-bird sprinklers, and collection pans. Two wedge gages, installed with mouths at top of vegetational canopy height, were placed 3 m to the north and south of each rain-bird sprinkler (three in center of picture) and were collocated with pans for throughfall measurement (e.g. on each side of center sprinkler). The taller rain gages (three to the right and one to the left of center) were not used in this experiment.

The research effort during the first season was designed to develop metholologies to determine water retained by the canopy and that which reaches the ground. The methods used and the preliminary results obtained are described.

Water Retention by the Canopy. Water retained on or in plants was measured as the difference between water content before sprinkling and the water content immediately after sprinkling. Both before and after sprinkling, samples of plants were transferred to plastic bags; dry weights of bags of plants were subtracted from wet weights of bags of plants to determine how much water was added during sprinkling. Results were expressed as grams of water per 15 cm of row, gms per dry gram of plant, and gms per cm^2 of plant. Little water was lost in the transfer of wet plants to plastic bags.

Water retention measured immediately after sprinkling was 0.8 ± 0.15 (SE) gm per gm of plant material (Table III-3) and did not appear to be related to temperature, humidity, radiation, or developmental stage. For 8 mm showers water retention increased with increasing amounts of vegetation: early season catches were 0.1 to 0.2 mm while late season catches were 0.4 to 0.8 mm in 15 cm (6 in) rows; half that in 30 cm rows, and one-third that in 45 cm rows. One may speculate that the plant-water-holding-capacity is saturated after the first one to three millimeters of water have fallen and that the catch doesn't increase after saturation. This is easily testable, and should be tested.

Water Reaching the Ground. A study of the literature showed that water reaching the ground has been measured by two methods: directly and indirectly as the precipitation minus canopy catch. To make a direct measurement a pan is inserted over the soil and under the vegetation without disturbing the plants. One approach is to first cut the plants, place a pan on the clipped plot, and then replace the plants with wire screening to hold them in their natural configuration (Clark 1940). (We doubt that we can produce a natural plant configuration by this method or that we can estimate the effects of deviations from the natural configuration.) A second approach is to surround the experimental plot with a metal lip and pour a sealer over the ground between the plants and metal lip (Merriam 1961). (We were unable to create pans which would hold water by this method whether we used paraffin, silicone rubber, casting plastic, or plaster-of-paris covered with any of these sealers.)

A variant of the first direct approach was used to measure throughfall and stemflow in barley. Precipitation was caught in metal pans (30 x 104 x 7 cm) placed under the crop. To get undisturbed (natural configuration) plants into the pans, plaster-of-paris was poured in blocks (29 x 15 x 2 cm) around the bases of the plants, lifted and cleaned, dipped in melted paraffin to waterproof them, and placed in the pans. Before use, the rootless plants were sprinkled to prevent wilt. Open spaces in the throughfall gage between rows were covered with wire mesh (1.5 mm) to reduce splashout.

A simple variant of the second direct approach was also used to measure throughfall and stemflow in barley: the soil water content measured gravimetrically before irrigation was subtracted from that measured after irrigation, to determine what had been added. Two centimeter-diameter soil cores were taken,

TABLE III-3

PARTITIONING OF PRECIPITATION (mm) IN A BARLEY CANOPY

DATE & TIME[1]	EXPERIMENTAL RESULTS[2] 15 cm Row PPTN	15 cm Row LEAF	15 cm Row P-L	15 cm Row PAN	15 cm Row SOIL	30 cm Row PPTN	30 cm Row LEAF	30 cm Row P-L	30 cm Row PAN	30 cm Row SOIL	45 cm Row PPTN	45 cm Row LEAF	45 cm Row P-L	45 cm Row PAN	45 cm Row SOIL	ENVIRONMENTAL CONDITIONS[3] CLOUD	TEMP	RH	PLANT CONDITIONS[4] PHEN	HT	WT	L-A	T-A	CATCH
30 JN 1:35N[5]	7.6	--	--	7.1	--	8.4	--	--	7.4	--	7.1	--	--	7.1	--	30%	31	18	4 lf	15	136	1.90	2.30	
S[5]	7.4	--	--	6.4	--	7.4	--	--	7.1	--	5.8	--	--	5.0	--									
3:45N	14.2	--	--	10.7	--	10.2	--	--	8.1	--	6.1	--	--	4.8	--	--	31	18						
S	3.0	--	--	2.8	--	4.6	--	--	2.0	--	2.5	--	--	2.5	--									
1 JL 11:30N	4.1	--	--	2.3	--	4.8	--	--	3.0	--	4.1	--	--	3.0	--	0	25	39						
S	3.6	--	--	2.0	--	4.3	--	--	3.3	--	2.8	--	--	2.0	--									
12:55N	2.8	--	--	2.0	--	3.3	--	--	2.8	--	3.3	--	--	2.5	--	10%	25	42						
S	3.3	--	--	2.5	--	3.6	--	--	3.0	--	2.5	--	--	1.8	--									
1 JL 2:55N	6.9	0.15	6.7	5.6	4.9	6.8	0.07	6.7	5.3	6.4	6.1	0.05	6.0	5.1	7.6	20%	25	42						1.13
S	6.9	--	6.7	5.6	--	7.9	--	7.8	6.9	--	5.8	--	5.7	4.8	--									
3:00N	5.1	--	--	--	3.1	--	--	--	--	--	--	--	--	--	--	0	26	47						
S	5.8	--	--	--	5.8	--	--	--	--	--	--	--	--	--	--									
8 JL 11:30N	7.4	0.08	7.3	--	4.3	7.5	0.04	7.5	--	6.4	7.2	0.03	7.2	--	4.3	50%	20	54	6 lf bcot	25	255	3.57	4.31	0.35
S	9.0	--	8.9	--	6.6	11.4	--	11.4	--	7.8	7.7	--	7.7	--	6.5									
9 JL 12:30N	8.0	0.23	7.8	--	4.3	6.4	0.12	6.3	--	3.0	9.3	0.08	9.2	--	6.0	8	23	72						0.89
S	9.1	--	8.9	--	9.3	9.5	--	9.4	--	6.4	8.9	--	8.8	--	6.4									
27 JL 8:00N	7.6	0.78	6.8	5.8	6.1	7.6	0.39	7.2	7.1	6.5	10.4	0.22	10.2	8.4	4.1	0	20	51	fl	65	798	2.39	4.79	1.08
S	5.3	--	4.6	3.6	3.6	5.3	--	4.9	4.1	3.6	--	--	--	--	5.3									
28 JL 10:30N	7.1	0.38	6.7	6.4	4.5	7.6	0.19	7.4	6.1	6.9	7.6	0.13	7.5	6.4	1.5	0	18	46						0.45
S	6.4	--	6.0	5.8	4.9	7.6	--	7.4	6.1	5.4	8.6	--	8.5	6.1	2.6									
18 AG 10:30N	8.6	0.73	7.9	3.3	6.9	8.6	0.37	8.2	7.1	9.2	8.4	0.24	8.2	5.3	6.3	100%	24	77	ripen-ing	75	739	0.73	2.00	0.99
S	7.4	--	6.7	2.8	5.0	7.6	--	7.2	5.3	7.8	8.9	--	8.7	5.8	8.0									

[1]Daylight Savings Time
[2]Results are reported in mm. PPTN = Precipitation. P-L = precipitation minus water caught on leaves.
[3]Environmental conditions are reported as cloud (% cloud cover), temp (°C) and RH (% relative humidity). Winds were always light.
[4]Plant conditions reported include PHEN. (phenology - 4 leaf, 6 leaf, flowering and refining), HT (height in cm), WT (weight in gm/m^2), L-A (leaf area in m^2/m), T-A (leaf + stem area in m^2/mm) and CATCH (water caught on leaves in gms of water per gram of plant).
[5]Refers to North and South rain gages.

which were shallow but reached well beyond the wetting front (usually 7.5 cm deep). The usual sample consisted of six soil cores taken in the row and series of six soil cores taken parallel to the first at 7.5 cm (3 in) intervals till mid-row was reached. Half the between-row cores were taken on one side and half were taken on the other to eliminate directional wind or sprinkler effects. In the calculation of water added to the plot, data for all soil cores in a plot were averaged. Catches at 0, 7.5, 15, and 22.5 cm from the row were similar although those at 0 cm, (with stemflow) and 22.5 cm (with little leaf cover) may have been slightly higher.

The soil catch method is planned for 1977 because it is easier, it is adaptable to crop, range, and forest conditions, and its precision can be increased by taking more soil cores. The pan-catch and soil-catch methods rarely gave the same results for a given experiment (Table III-3), but on the average they gave comparable results for young plants or old plants in all row spacings (Table III-4).

Approximately 77 percent of a 8 mm shower falling into a barley field reaches the ground regardless of vegetative cover, e.g. plant size or row spacing (Table III-4 and Table III-3).

TABLE III-4

THROUGHFALL AS A PERCENTAGE OF PRECIPITATION
(Data in mm as well as environmental conditions appear in Table III-3)

		15 cm Row			30 cm Row			45 cm row		
		P-L[1]	PAN (%)	SOIL	P-L[1]	PAN (%)	SOIL	P-L[1]	PAN (%)	SOIL
30 June	1:35N	--	93	--	--	88	--	--	86	--
	S	--	86	--	--	96	--	--	86	--
	3:45N	--	75	--	--	79	--	--	79	--
	S	--	93	--	--	47	--	--	100	--
1 July	11:30N	--	56	--	--	70	--	--	73	--
	S	--	56	--	--	77	--	--	71	--
	12:56N	--	71	--	--	85	--	--	76	--
	S	--	76	--	--	83	--	--	72	--
1 July	2:55N	98	81	71	99	78	94	99	84	125
	S	98	81	--	99	87	--	99	83	--
3 July	3:00N	--	--	61	--	--	--	--	--	--
	S	--	--	100	--	--	--	--	--	--
8 July	11:30N	99	--	58	99	--	85	100	--	60
	S	99	--	73	100	--	68	100	--	84
9 July	12:30N	97	--	54	98	--	47	99	--	65
	S	97	--	102	99	--	67	99	--	72
MEAN[2]		98	77	74	99	79	72	99	81	81
SD		+1	+13	+20	+1	+13	+18	+1	+9	+20
27 July	8:00N	90	76	80	95	93	86	98	81	39
	S	85	68	68	93	77	68	--	--	--
28 July	12:00N	95	90	63	97	80	91	98	84	20
	S	94	91	71	97	80	71	90	71	30
18 Aug.	12:30N	92	38	80	94	83	107	97	63	75
	S	90	38	68	95	70	103	97	65	90
MEAN[3]		91	67	73	96	81	88	98	73	51
SD		+4	+24	+7	+2	+8	+16	+1	+9	+30

[1]Precipitation minus water present on leaves
[2]Throughfall in a young barley stand: Mean and standard deviation (SD)
[3]Throughfall in a near mature barley stand: Mean and standard deviaiton (SD)

DISCUSSION

If 20 to 30 percent (1.6 mm) of a 8 mm sprinkling shower does not reach the ground and only 3-12 percent (0.5 mm) of the shower is retained by the canopy, water must evaporate rapidly during the shower. Such evaporation rates seem possible: 1) if dry 10 cm grass can lose about 6 mm/day (e.g. McIlroy, Angus 1964) then wet barley could likely lose 1 mm per half hour; 2) rain falling from thundershowers commonly evaporates before reaching the ground (virga) and the relative humidity in one rain-shower was 48 percent; 3) one can sometimes see "flash evaporate" in the field (see below). Evaporative losses observed may have been higher than these normally associated with thundershowers because our sprinkling studies were conducted under relatively cloud-free, and relatively warm conditions, (although inspite of light winds and relatively high humidities) and were subject to oasis effects.

The amount of water retained in a barley canopy increases as the amount of vegetation increases (crop development or narrower rows) but water falling to the soil appears to remain reasonably constant with increasing amounts of vegetation. This can be so only if evaporation rates are higher in thin vegetation than in relatively dense vegetation. This, in turn, seems possible because: 1) radiation falling on a thin stand warms soil not exposed to cooling winds, while radiation falling on a dense stand warms a canopy which is more exposed to cooling winds, (conduction and convection losses are high e.g. Geiger 1965, Gates 1972); 2) evapotranspiration from a dense stand dissipates more of the energy falling on it than does evapotranspiration from a thin stand; 3) either factor might result in higher soil (and air?) temperatures capable of "flash evaporating" water falling into the open stand. One observation supports this hypothesis: On July 28, 1976, in a recently irrigated barley field (45 cm rows), water fell to the ground, spread slightly, and flash evaporated to produce a slight haze near the ground (conditions: 0% clouds, still, 18°C, RH 46%).

The preliminary results described above suggest several questions: 1) What evaporation rates exist in the canopy under different (storm vs non-storm conditions? These rates will determine the amount of throughfall and the length of time water held in the canopy will shield the community from further water loss. 2) Is a significant part of canopy catch absorbed?; a measurement of maximum absorption rate will probably show that it is not. 3) How much throughfall reaches the ground under storms of different sizes (5, 10, and 15 mm)? 4) How quickly is the water from a light summer shower dissipated? This question can probably be answered best by lysimetry and reasonable answers might be found in existing data. The questions are probably listed in inverse order of importance. Studies of plant responses to light summer showers such as extensions of those described in the following reports will receive more attention in 1977.

Effects of Summer Showers on Water Potential of Crops and Range Plants

Preliminary Report: October, 1976

Tad Weaver and John Newbauer

INTRODUCTION

Land Plants take in CO_2 through their stomates and, by photosynthesis, convert it to sugars and other materials necessary for growth. When plants are dry, their stomates close to prevent excessive drying. Stomate closure restricts the availability of CO_2, stops photosynthesis, and halts growth. The water stress a plant feels is expressed in "bars" and may be measured with a Scholander pressure bomb (Scholander et al 1965, Tobiessen 1969). For many plants photosynthesis and growth are reduced significantly when water stresses exceed 2 to 10 bars.

This preliminary study described below was designed to investigate what effects showers--such as those that might result from cloud seeding--would have on plants suffering drought stress.

METHODS

The vegetation types studied were a barley field near Bozeman, Montana, and several native ranges near Miles City, Montana. Rows in the barley field were 15 cm (6 in) apart; in two plots, alternate rows were pulled to create a 30 cm spacing and in two other plots, two of three rows were pulled to create a 45 cm spacing.

The effects of about 8 mm (0.3 in) showers were studied by examining the effects of natural showers or by sprinkler irrigating small plots.

The size of natural and artificial showers was determined with level wedge gages with mouths at the top of the vegetational canopy. In some cases the delivery of water to soil was also determined by gravimetric methods: the water content in soil cores taken before irrigation was subtracted from the water content of soil cores taken after irrigation and the resultant increase was expressed in centimeters of water.

The effects of sprinkling on plant water potentials were determined by contrasting the water potentials of plants in irrigated plots with others in adjacent unirrigated plots. Water potentials were measured with a Scholander pressure bomb (Scholander et al 1965).

To demonstrate that small amounts of water are absorbed through barley leaves, two samples of barley were cut at ground level and placed in plastic bags in the shade (to minimize transpiration); one sample was submerged, except for its cut bases, in water (to permit absorption of water through the leaf surface); and the water potentials of the samples were compared.

RESULTS AND DISCUSSION

Water Potentials. It has been noted above that the water stress of a plant determines its performance. Water stresses below 10 bars are required for significant photosynthesis and growth of crop plants (Bris 1962). Other plants may have higher critical levels; critical levels of the range plants considered below have not yet been determined.

The water stress (or water potential[1]) experienced by a plant is determined by the rate of water absorption by its roots and the rate of water loss from its shoot. At a given soil water content (=absorption rate) water stresses are low in the morning and evening when transpiration rates are low and relatively high in the afternoon when transpiration rates are higher than absorption rates; data from July 13-16 illustrate this phenomenon for barley (Table III-5). At similar transpiration rates (similar radiation - temperature - wind), plants with high absorption rates (moist soils) should have lower water stresses than others with low absorption rates (dry soils); for example, Table III-5 shows that water stresses recorded at 2 p.m. in barley were high before the rain of July 13 (July 8 and 9), were lowered by that rain (July 13), and rose again as the soil dried (July 15 and 16). The low water stresses of July 17 were due to low radiation stress (100 percent cloud cover).

Immediate Effects of Irrigation. Even the lightest rainshower should produce an immediate drop in plant water stresses for three reasons: transpiration rates will be lower under cloud cover (lower radiation and temperature); energy available for evaporation will be used in evaporating water from leaf surfaces rather than from the plant itself; and some water may be absorbed through the leaf surface. Even under cloudless skies (July 3 and 9) where the first mechanism is inoperative, drop in water stress (water potential) was observed during irrigation: stresses were reduced by 5 bars on Site I; by 3 bars on Site II; and 6 bars on Site III (Table III-6).

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[1]"water stress" and "water potential" are used as synonyms even though some prefer expressing "water potential" in negative bars.

TABLE III-5

Effect of a natural shower on the daily pattern of water potential (bars) in barley. The 8. mm = (0.3 in) shower occurred during the night of July 12-13.

Date	8 July	9 July	13 July	14 July	15 July	16 July	17 July
% cloud cover	30-50	20-50	0	0-5	0	0-5	100
noon RH	54%	70%	56%	56%	65%	52%	72%
noon wind	light	light	light	breezy	windy	still	still
6 am						0.5±0	
8 am			2±1	4±2	6±2		
10 am			6±1	9±2	10±1	13±2	
12 noon	15±1	11±1	10±1	12±1	13±1	16±2	9±2
2 pm	14±2	16±1	11±1	11±1	14±2	17±1	
4 pm	15±1		11±1			18±1	
6 pm		13±3	11±2	14±1	16±1	19±1	
8 pm	5±2	7±1	8±1			10±1	
10 pm			1±1	4±1	5±1	6±1	

TABLE III-6. Water potentials (bars) of barley before, during, and after sprinkling compared with water potentials of unirrigated barley plants.

	SITE I		SITE II		SITE III	
DATE	3 July[1]		8 July[1,2]		9 July[1]	
Treatment[3]	unirr	irr	unirr	irr	unirr	irr
11 am	--	--	13±5	15±1[b]	11±1	11±0[b]
12 noon	--	--	14±1	11±3[d]	11±1	5±1[d]
2 pm	18±1	19±2[b]	--	--	16±1	13±2[a]
3 pm	18±1	13±3[d]	--	--	--	--
4 pm	16±1	12±1[a]	15±1	15±1[a]	--	--
6 pm	16±1	14±1	--	--	13±2	10±0
8 pm	--	--	5±2	8±2	7±1	5±1
10 pm	4±1	3±0	--	--	--	--

[1]irrigation equaled approximately 6.4 mm on Site I, 2.6 mm on Site II, and 8.9 mm on Site III.

[2]water stresses were lower on the irrigated than on the unirrigated plot of Site II on the following day (9 July):

Time	11 a.m.	1 p.m.	2 p.m.	6 p.m.	8 p.m.
Unirr	11±1	11±1	16±1	13±2	7±1
Irr	10±1	12±0	14±2	11±0	5±1

[3]treatments are irrigated and unirrigated

[b]before irrigation

[d]during irrigation

[a]after irrigation

Absorption of water through the leaf surface is often regarded as non-existant or insignificant. To determine whether it might have contributed to observed reduction of water stress, samples of barley at ground level (to eliminate absorption) were cut, placed in plastic bags in the shade (to minimize transpiration), submerged all but the cut ends of half the stems in water (to permit absorption through the leaf surface only), and the water potentials of those exposed to water and those not exposed to water were contrasted. Water potentials of unsoaked bagged plants changed little from those observed in the field. Water potentials of those soaked in water were lower than those not exposed to water (Table III-7), so water must have been absorbed through the leaf surface. Water potentials of plants exposed to water were, however, only slightly lower than those not exposed (Table III-7), so absorption rates must have been low and probably not biologically significant. A planned refinement of this method should indicate leaf absorption rates.

The immediate drops in water stress observed after irrigation (refer to Table III-6) were more than likely insufficient to produce significant increases in photosynthesis. It is generally held that stomates close and photosynthetic rates drop as water stresses rise above 2 to 10 bars (e.g., Milthorpe and Moorby 1974). Water potentials observed during our irrigation treatments decreased to 13 bars on July 3, 11 bars on July 8, and 5 bars on cloudier July 9.

TABLE III-7

EFFECT OF WETTING LEAF SURFACES ON WATER STRESSES (BARS) OF BARLEY

Field Conditions		Cut Leaves Unsoaked	Cut Leaves Soaked	Minutes Soaked
8 July	14±1	15±3	10±2	3
16 July	18±1	20±2	9±3	5
16 July	18±1	17±1	9±4	10

Longer Term Effects of Irrigation. While the immediate effects of a shower are expected to affect water stresses through effects on the canopy (shade, reduced transpiration, and absorption), the longer term effects of a shower should affect water stress by increasing water availability and absorption in the root zone.

Irrigation of approximately 8.0 mm (0.30 in) applied to a barley field suggested that light to moderate summer rains will reduce water stresses but that these effects may not be large enough to increase growth. In a relatively dry barley field water stresses were lowered 2-3 bars immediately after irrigation and at least 1-2 bars on the following day (Table III-6). Due to the "oasis or clothes-line effects", long term (2-3 day) effects of light showers are probably considerably underestimated by irrigation of small plots; Table III-5 suggests that positive effects of a natural 8 mm (0.3 in) shower in July might be felt for at least three days. Note, however, that most data in both tables III-5 and III-6 show water stresses above ten bars; e.g. water stresses at which photosynthesis

and growth are commonly thought to be insignificant for barley. We recommend that this hypothesis be tested.

Artificial sprinkling of 2.5, 5.0, and 12.7 mm (0.1, 0.2, and 0.5 in) was applied to dry native ranges of eastern Montana to determine whether they were more efficient users of water than the preliminary results indicated for barley. The experiment of July 21-23 (Table III-8) suggests three conclusions: 1) Water stresses in western wheatgrass (Agropyron smithii) will be reduced in the intermediate (half-day) and long (2-3 day) term by irrigation in the 2.5 to 12.5 mm range. 2) Because water evapotranspires more rapidly from small plots than it would from larger areas of rangeland irrigated by natural showers, the beneficial effects of a shower should last longer than those of small plot irrigation. 3) Even a 12.7 mm (0.5 in) rain may provide little benefit at certain times during the growing season, if photosynthesis and growth of certain range plants are as restricted by water stresses above 10 bars as crop plants are. The experiments of July 27, August 11, and August 12 reinforce these conclusions and extend them to blue grama (Bouteloua gracilis) and needleandthread (Stipa comata), two other range grasses important in the area (Table III-8). However, some data suggest that range and desert plants may continue to grow at higher water stresses (e.g., Odening et al 1974, Van Den Driessche 1971.

Because plant responses (photosynthesis and growth) to water stress must be known to determine the timing and the amount of rainfall needed to be useful, these questions are being pursued in subprojects which are in progress or being planned.

Explanation of small effects. If showers in the 2.5 to 12.7 mm (0.1 to 0.5 in) range at times during the growing season have little positive effect on crop and range plants suffering from drought, it is important to ask why. Four hypotheses are advanced below.

1. None of the water reaches the soil. Though the interception of water by vegetation is the subject of another subproject (Weaver and Newbauer), data from two experiments presented here obviously show that water does enter the soil. In a barley field studied on July 1, 50 to 80 percent of the water applied reached the soil; most of which apparently stayed in the upper 5 cm (2 in) of the soil (Table III-9). In a western wheatgrass range studied on July 21, 50 to 90 percent of the water applied reached the soil; all of the water apparently stayed in the upper 5 cm of the soil (Table III-9). Since both measurements of water added were made within hours of the irrigation, some of the water entering the soil may have later percolated into the 5-10 cm (2-4 in) layer.

2. Perhaps there are no roots in that thin surface soil layer which is wetted by light showers. The depth to which 2.5 mm (0.1 in) of rain will wet a soil depends on the water holding capacity of the soil and might be 0.75 cm (for a soil with 50 percent clay and 5 percent organic matter) to 3.3 cm (for a sand with 10 percent clay and no organic matter (Decker 1972). A survey of a wide variety of vegetation types --blue grama, needleandthread, bluebunch wheatgrass (Agropyron spicatum, Idaho fescue (Festuca idahoensis), alfalfa, barley, douglas fir, (Pseudotsuga menziesii), and alpine tundra--suggests that roots are in fact rare in the uppermost 1 to 2 cm of the soil, that they are most common at approximately 5 to 10 cm, and that they are less common in deeper layers. Hard data for this observation are not available for this report, but the lack of roots in the uppermost soil layers seems likely because those layers are usually dry and the water available to surface roots may have less value than the energy cost of synthesis of roots in these layers.

TABLE III-8. Effect of irrigation on water potentials (bars) of important range grasses experiencing drought.

Time[1]		7 a.m.				8 a.m.				9 a.m.				10 a.m.			
Treatment[2]		cont	2.5	5.0	12.7mm	cont	2.5	5.0	12.7mm	cont	2.5	5.0	12.7	cont	2.5	5.0	12.7mm
A. smithii[3]	21 July[4]	40+	--	--	19 ±13	40+	33 ±4	17 ±0	13 ±4	--	--	--	--	--	--	--	--
	22 July[4]	31 ±4	26 ±2	16 ±0	15 ±6	40 ±1	38	26 ±11	21 ±1	40+	35	35 ±2	20 ±8	40+	40+	35 ±3	24 ±2
	23 July[4]	40+	37 ±4	25 ±3	18 ±6	40+	39 ±2	33 ±3	20 ±5	40+	40+	35 ±4	24 ±9	--	--	--	--
A. smithii	27 July[5]	40+	37 ±4	31 ±5	24 ±5	40+	40+	38 ±2	34 ±3	40+	40+	40+	32 ±4	40+	40+	37 ±3	32 ±5
S. comata	11 Aug.[5]	25 ±9	29 ±5	31 ±6	15 ±8	--	32 ±9	26 ±5	17 ±10	--	32 ±10	26 ±7	28 ±9	40+	40+	39 ±2	34 ±5
S. comata	12 Aug.[5]	--	--	--	--	40+ ±1	--	--	33 ±4	40+	--	--	30 ±8	40+	--	--	31 ±8
B. gracilis	12 Aug.[5]	21 ±4	10 ±2	6 ±2	8 ±3	29 ±9	11 ±6	7 ±4	16 ±12	30 ±10	22 ±12	12 ±6	13 ±7	27 ±11	17 ±4	11 ±2	18 ±8

[1]Times recorded are a.m. except for 21 July where they are p.m .

[2]Treatments were irrigations of approximately 0, 2.5, 5.0, and 12.7 mm; see footnotes 4 and 5.

[3]Species studied were Agropyron smithii, Stipa comata, and Bouteloua gracilis.(Water potential expressed in bars ± S.D.

[4]Actual precipitation on 21 July was 0, 2.5, 5.0 and 15.2 mm; readings on 22 and 23 July are due to the same irrigation.

[5]Actual precipitation on 27 July was 0, 2.8, 7.6, and 11.7 mm. Actual precipitation on 11 August was 0, 2.5, 5.6, and 12.2mm. Actual precipitation on 12 August was 0, 2.5, 5.0, and 11.7mm.

TABLE III-9

Water reaching the soil in two irrigation experiments. Soil water contents were determined soon after the irrigation; some of the water added to the 0.5 cm (0-2 in) layer may have later percolated down into the 5-10 cm (2-4 in) layer.

Experiment		PPTN	% in Soil	Water Added To 0-5cm	Water Added To 5-10 cm
1 July[1]	15 cm barley rows	0.84 cm	81	0.54	0.14
	30 cm barley rows	0.64 cm	72	0.46	0.00
	45 cm barley rows	1.27 cm	53	0.55	0.12
21 July[2]	_A. smithii_ field	0.25 cm	88	0.22	0.00
		0.50 cm	54	0.27	0.00
		1.27 cm	63	0.80	0.00

[1]Conditions were similar to the 3 July experiment reported in Table III-2. The soil was a silt-loam

[2]Water potentials recorded in this experiment are reported in Table III-4.

3. Perhaps roots in the uppermost soil layers are dead or suberized at midsummer and are in no condition to absorb water made available to them. Death or suberization would prevent transfer of water from the plant to dry soils in between-shower periods. Death or suberization might be induced by soil drought (Ares 1975) and/or photoperiodic or temperature-induced inherent responses of the season; another subproject (Forcella and Weaver) may shed light on the latter possibility. If absorbing roots don't exist in moist layers, absorption and reduction of water stresses must await growth of new roots which may or may not appear before precipitation added by the shower has evaporated off. Possibly the time span between showers may offset the time required for root initiation and growth into deeper, moist soil layers. This phenomenon is alluded to with general vegetative responses to watering and after drought stress in several grass species (Forcella and Weaver).

4. Perhaps roots do absorb water from the soil but valves in the plant prevent transport to the shoot. This possibility 1) is logically acceptable, 2) would have survival value as a mechanism to prevent dessication of roots in seasons when soil water could not support shoot transpiration, but 3) to our knowledge, has not been observed in non-deciduous species.

Further Studies

This study produced some interesting results that demand clarification. 1) Our preliminary results suggest that even 12 hours after applying 12 mm of water by sprinkling during the period studied (July and August) water potentials remained greater than 10 bars except for blue grama on August 12 (Table III-8). However, it is not known if photosynthesis of range grasses are halted at water stresses greater than 10 bars during this period. To determine this, photosynthetic rates of common range plants need to be compared with high and low

leaf water potentials. The following report (Forcella and Weaver) shows little correlation between growth and soil water potentials. 2) Due to the "oasis effect" measurements of the water potential were made only 12 hours following the application of water. Therefore, it seems imperative that both water potentials and growth of important range grasses be monitored for a longer period after natural and artifical storms to determine which seasons the plants respond and when maximum water potential reduction is achieved. 3) If plants cannot respond to water in July and August, explanations should be sought; are roots unavailable in the moist soil layers (measurements in progress); are available roots currently functional (methods available); and are daylength and/or temperatures inappropriate for growth (see Forcella and Weaver)? Most of these questions were anticipated; experiments to answer them are underway.

Water Relations of Montana Range Grasses

Preliminary Report - October 1976

Frank Forcella and Tad Weaver

INTRODUCTION

Plants obviously respond to water, though much is still to be learned about the phenological states at which they respond, the degree to which they respond, and the factors controlling their responses.

The response of native grass plants to added precipitation (e.g., weather modification) will depend upon the factors which control dormancy in summer-active and summer-dormant species (warm and cool-season species respectively). For example, 1) if day-length controls dormancy and if summer precipitation is increased, the summer active plants will have a competitive advantage (by default) for this additional moisture. These plants would likely increase in importance and thereby increase their resource utilization at the expense of the summer-dormant grasses. 2) On the other hand, if summer-dormancy is induced by drought stress, additional precipitation may prevent or break dormancy. If this were the case, both groups of plants would be physiologically active and their differential responses (if any) would be a function of the "aggressiveness" of their water absorption capabilities.

It would be of considerable economic importance that if warm-season grasses were to increase on Montana rangelands, the grazing potentials for cattle would decrease, in turn necessitating increase management efforts. Ecophysiological information about range grass will therefore be applicable.

METHODS

In these experiments five grass genera were chosen; each genus has two species differing in water requirements. The "species pairs" included here are blue grama (<u>Bouteloua gracilis</u>), sideoats grama (<u>B. curtipendula</u>); little bluestem (<u>Andropogon scoparius</u>), big bluestem (<u>A. Gerardi</u>); needleandthread (<u>Stipa comata</u>), green needlegrass (<u>S. viridula</u>); western wheatgrass (<u>Agropyron smithii</u>), bluebunch wheatgrass (<u>A. spicatum</u>); and Idaho fescue (<u>Festuca idahoensis</u>), rough fescue (<u>F. scabrella</u>). The first two genera are warm-season grasses and the remaining three genera cool-season grasses. The first species in each pair mentioned above is normally thought to be the "drier" of the two, though there is some debate on this.

Experimental procedures will be described under two headings--both conducted under controlled conditions in a greenhouse; (1) The Light Experiment, and (2) The Water Experiment.

The Light Experiment. In this experiment the responses of important Montana range grasses to short and long-days were compared. Each treatment contained six individuals of the following species: little bluestem, blue grama, needleandthread, bluebunch wheatgrass and western wheatgrass. Both treatments received 12 hours of daylight, but the long-day treatment received a light flash eight hours before the beginning of its 12-hour daylight period. The light flash was of low intensity and lasted only 1 hour, so the total energy balance of the two photoperiod treatments was not significantly different.

To determine the effects of flowering on vegetative growth, we clipped all flowering culms from half the individuals (three) of each of the five species as soon as they could be distinguished.

Vegetative response was determined by measuring leaf and culm elongation of all leaves on each of three culms per plant. Only the most vigorous culms were measured; these were constantly changed so senescent culms were never sampled. Measurements were made with a millimeter ruler and were accurate to within 0.5 mm. Measurements originated at the leaf collar. The plants were moved twice weekly to exclude the effects of microclimatic gradients which might have existed in the greenhouse. The average ($\pm$ S.D.) growth rate per culm per day for each plant was calculated for each growth period.

The Water Experiment. In this experiment the grasses (six individuals per species of ten species) were subjected to a 12-hour photoperiod (cf. Light Expt.). We allowed soil to be depleted of water until growth (leaf and culm elongation) stopped or wilting was observed. At this point the plants were subirrigated to bring their soils to field capacity. The time period from one water application to the next is referred to as a "watering cycle." Soil water potentials were monitored with double junction thermocouple phychrometers from J.R.D. Merrill Speciality Equipment.

The vegetative response to water stress cycles was measured as in the Light Experiment, except that 5 culms on each plant were monitored.

Flowering culms from one-half of the individuals of each species were removed upon first observation to prevent a respiratory and structural drain. This allowed comparison of response of flowering and non-flowering populations.

The experiment is now being repeated under both long and short days.

RESULTS: LIGHT EXPERIMENT

Anthesis. The flowering response of grasses to photoperiods is generally well known (Omstead 144, Larsen 1947, Wareing 1956, MacMillan 1955, Jewiss 1972). Since the plants from each species in the experiments were collected from the same population, ecotypic variation is expected to have little effect.

The flowering responses of the plants were those expected for the warm and cool-season grasses (Table III-10). Warm-season grasses are normally thought

to be obligate long-day plants, while cool-season grasses are facultatively short-day (Heady 1975). Some grasses, such as western wheatgrass, are known to produce an extremely high proportion of vegetative culms (Heady 1975); indeed, this species produced no reproductive culms under either photoperiods in the experiments (Table III-10).

TABLE III-10

The flowering response (%) of five grass species in relation to the photoperiod at which they were grown. Short day = 12 hours natural daylight, Long day = 12 hours natural daylight plus single light flash. The first two taxa are warm season grasses, the last three are cool season grasses

Grasses	Short-day	Long-day
Little bluestem	0	67
Blue grama	0	83
Needleandthread	83	50
Bluebunch wheatgrass	50	50
Western wheatgrass	0	0

Vegetative Growth. Vegetative responses of grasses to photoperiod manipulations have received less attention than reproductive responses and are therefore less understood. Vegetative response of grass plants to photoperiod involves tiller formation and leaf elongation. Both responses are hormonally controlled (Jewiss 1972); auxins inhibit, while gibberillins, cytokinins and auxin antagonists promote tiller formation and subsequent leaf elongation. Hormone production and/or localization is mediated through photoperiod and vernalization in at least some perennial grasses (Jewiss 1972).

Table III-11 shows the vegetative responses of five grasses to photoperiod. The warm-season grasses (little bluestem and blue grama) grew much better under the 16-hour photoperiod. In these grasses, all tillers present at the beginning of the experiment elongated rapidly under the 16-hour photoperiods but no new tillers were produced. Toward the end of the experiment, little growth occurred under the long-days because these grasses lacked the formation of new culms (tillers). Two cool-season grasses, (bluebunch wheatgrass and needleandthread) also grew significantly better under long-days. Since tiller formation was not inhibited in these two species, vegetative growth remained active throughout the experiment. In contrast, a third cool-season grass, (western wheatgrass), responded equally well under both photoperiods. Shoot initiation and rhizome extension were enhanced with short-days in western wheatgrass, but this vegetative response was compensated for by a greater leaf elongation under long-days. This response of western wheatgrass will be further studied.

Data from these experiments will be analyzed when they are more complete. They now suggest that under long-days, (Table III-11) growth was immediately stimulated in bluebunch wheatgrass and needleandthread (formerly given short-days),

TABLE III-11

Leaf elongation (mm/culm/day) of five grass species in relation to the photoperiod at which they were grown. Short day = 12 hours natural daylight; Long day = 12 hours natural daylight plus single light flash

Grasses	Short-day mean	S.D.	Long-day mean	S.D.
Little bluestem	0.1	$\pm$ 0.2	7.4	$\pm$ 4.5
Blue grama	0.2	$\pm$ 0.7	5.4	$\pm$ 2.6
Needleandthread	3.2	$\pm$ 1.8	6.1	$\pm$ 2.8
Bluebunch wheatgrass	3.9	$\pm$ 2.7	10.6	$\pm$ 4.4
Western wheatgrass	8.6	$\pm$ 3.6	11.3	$\pm$ 3.4

and repressed in former long-day individuals of the same taxa now given short-days; both plants grow best under long-day regimes. For blue grama, an approximate 30-day delay occurred before individuals repressed under short-day treatments responded to the long-days. Growth in these individuals is presently progressing at rates comparable to their counterparts given long-days in the original experiment.

Leaf elongation of repressed short-day little bluestem was not stimulated by exposure of plant to long-days created by breaking the night (as above), but was initiated if the plants were exposed to continuous daylengths of 24 hours. Rapid growth was normally apparent within seven days of the initiation of these photoperiods.

Tiller formation in warm-season grasses formerly given long-days and transferred to short-days has not yet occurred.

Effect of Anthesis on Vegetative Growth. Table III-12 compares leaf elongation of plants allowed to flower with those from which juvenile flowering culms were constantly cut. There were no significant differences in vegetative growth in any of the species under either short or long-days.

During the second week of August 1976, the photoperiods of the plants treated with long and short-days were reversed to determine whether photoperiods alone will stimulate previously repressed individuals and re-stimulate tiller formation in warm-season grasses which had grown rapidly and were not dormant. Other plants are being vernalized (1-2^{o}C) because some grasses require a "cold treatment" for tiller initiation and/or leaf expansion. The responses of still other plants to continuous (no light flash) 16 hour photoperiod are also being observed.

TABLE III-12

The vegetative growth (mm/culm/day) of four grass species in relation to their flowering and non-flowering conditions

Grasses	Short-day				Long-day			
	Flowering		Non-Flowering		Flowering		Non-Flowering	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Little bluestem	--	--	--	--	9.9	± 5.8	6.1	± 3.2
Blue grama	--	--	--	--	5.6	± 3.0	5.2	± 2.3
Needleandthread	2.7	± 0.7	3.8	± 2.4	7.2	± 3.6	5.1	± 1.3
Bluebunch wheatgrass	3.2	± 2.7	4.6	± 2.7	9.7	± 3.6	11.4	± 5.2

CONCLUSIONS: LIGHT EXPERIMENT

With respect to weather modification, the management implications of the results of photoperiod manipulations on the vegetative growth of important Northern Great Plains range grasses are: 1) Alleviation of drought stress (rainfall) during the naturally long photoperiods of midsummer would do little to increase overall productivity of little bluestem and blue grama, if early summer soil moisture was sufficient to initiate vegetative growth--photoperiod would still restrict tiller formation. 2) Summer-time enhancement of soil moisture should promote vegetative growth in needleandthread and bluebunch wheatgrass because; i) these grasses continually produce new tillers under long and short-days, and ii) leaf elongation is enhanced under long-days. 3) Summer-time moderation of soil moisture stress would increase leaf production in western wheatgrass. However, rhizome and tiller initiation would not be as greatly affected as leaf elongation in this species.

It appears then that the vegetative growth of cool-season grasses would tend to be favored by summer-time weather modification over that of warm-season grasses. In Montana, the cool-season range grasses are the most desirable and palatable for livestock, so such effects are probably desirable.

RESULTS: WATER EXPERIMENT

The synthesis and presentation of the "Water Experiment" results are complicated because: 1) the experiment has not yet been completed and 2) comparison of data are difficult because of differences in both absolute growth rates and watering cycle lengths within individuals and species. To solve the second problem, absolute growth rates were converted to percent of maximum growth rate for each watering cycle of individual plants. Since watering cycle lengths varied little for a particular species, mean cycle length was used in presenting the data.

As an example of a single watering cycle, Fig. III-8 depicts the absolute response (leaf growth rate in mm/culm/day) of western wheatgrass to a single water application (at Time = 0, growth rate = 0). Note that 1) the growth response is skewed; growth is best a moderate time after watering, and 2) the growth response seems to be partly correlated with soil water potential (as monitored with thermocouple psychrometers). The shapes of both curves, (growth rate and water potential) are characteristic of the data but the distribution and magnitude of the data along the coordinates differ according to the species, individual plants and individual watering cycles.

Figures III-9-15 represent the "composite" response (percent maximum growth rate) for each species in relation to the amount of time elapsed from a single water application. (The line of the growth response of each species was arbitrarily drawn). The most important phenomemon demonstrated is a lag in plant response to watering.

The lag period may be due to oxygen deficiency, stomate opening, repair of protoplasm, repair of roots, or rebuilding of carbohydrate reserved. 1) Immediately after watering, soil may lack oxygen due to flooding. The lag period is often more than two days, so explanations other than asphyxiation are also required. 2) Stalfelt (1964) believes that upon rewatering, full turgor is restored to the plant; thereafter a slight loss of turgor will occur, whereupon the stomates will open even wider to permit more rapid absorption of CO_2, more rapid photosysnthesis, and greater growth. 3) It is also well known that drought stress inhibits mitochondrial, chloroplast, ribosomal, etc. activity (McClendron and Blinks 1952, Virgin 1964, Gardner and Nieman 1964). The observed staggered response to leaf elongation may be due to the necessity of physiological repair mechanisms operating in advance of the resumption of maximal growth. 4) Roots are killed by the water stresses incurred and those absorbing organs would have to be replaced. 5) A further possibility might be that during water stress, the total reserved carbohydrates available in the plants are reduced due to the lack of net photosynthesis (Woodhams and Kozlowskii 1954). It may be that the lag time is a response to this depletion of reserved potential energy. That is, maximal growth is resumed only when some restoration of the former carbohydrate balance is made.

Two aspects of the lag period are important in estimating the effects of weather modification on native range. Plants first adapt to increasing drought with easily reversible changes and later with more slowly reversible "hardening" (Stocker 1960). Plants which remain in the dehardened phase under dry conditions and/or plants which deharden very quickly will respond quickly to a shower; while plants which harden under slight water stress and deharden slowly will respond more slowly to a shower. Rapidity of response to rewatering is an integrated measure of non-hardening and dehardening rates (cf. Greber 1964). Such measurements should indicate which species will respond rapidly to an increased frequency of showers. Blue grama (Fig. III-15) shows a high growth rate one day after rewatering, but comparative data for sideoats grama are not yet available. Western wheatgrass responds more rapidly than bluebunch wheatgrass (Figs. III-9-10); green needlegrass responds more rapidly than needleandthread (Figs. III-11 and 12); and rough fescue responds more rapidly than Idaho fescue (Figs. III-13 and 14).

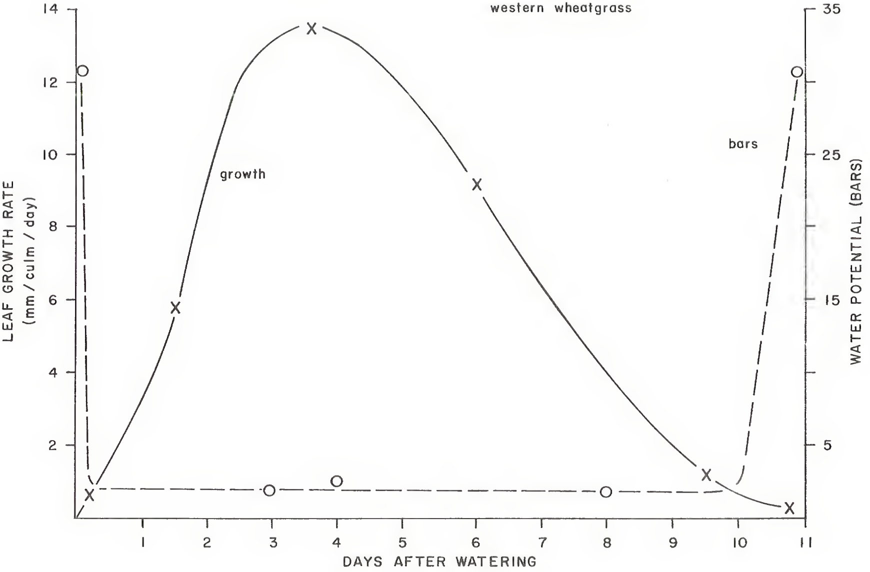
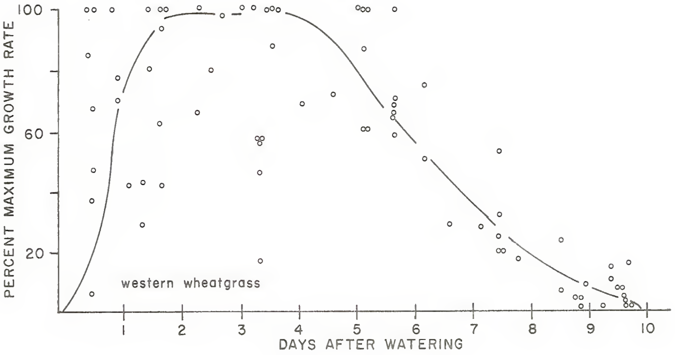
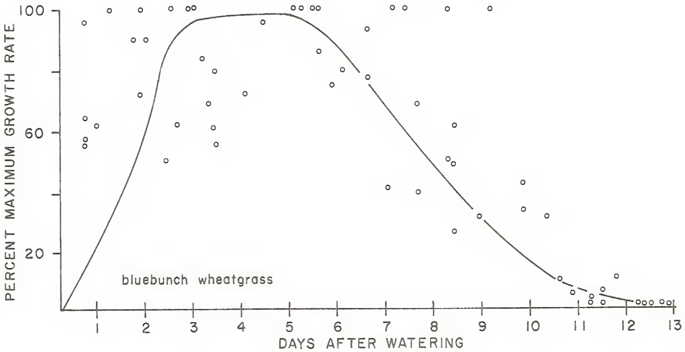
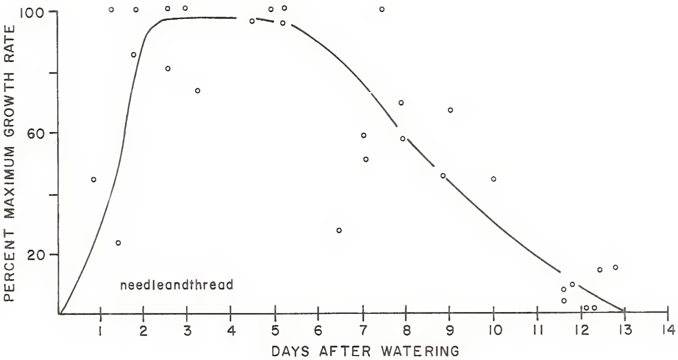


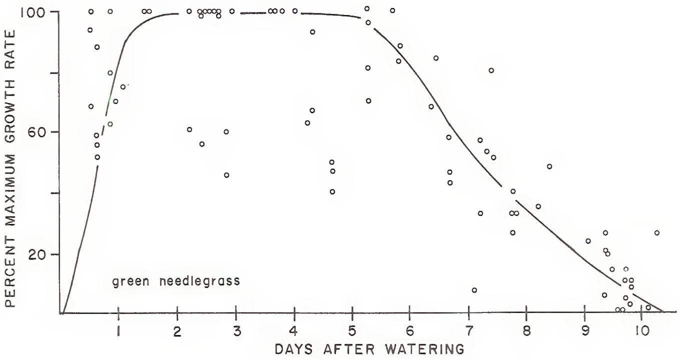
Figure III-8. Representative growth response of western wheatgrass to a single water application (day 0) and to soil-water potential.



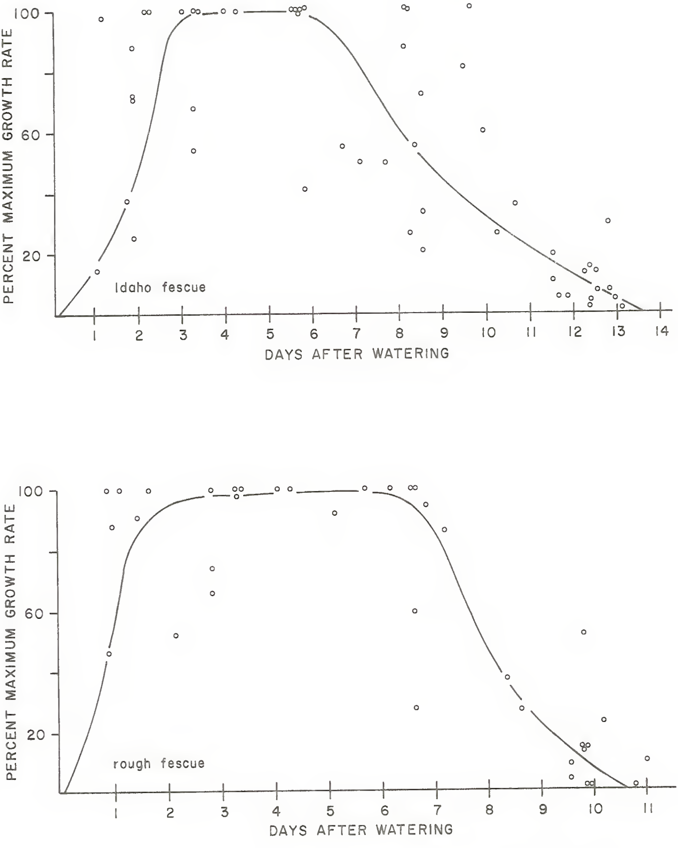


Figures III-9 and 10. The growth responses of western wheatgrass and bluebunch wheatgrass to a single application of water (day 0). The ordinate represents the percent of the maximum growth rate (per day) obtained.





Figures II-11 and 12. The growth responses of needleandthread and green needlegrass to a single application of water (day 0). The ordinate represents the percent of the maximum growth rate (per day) obtained.



Figures III-13 and 14. The growth responses of Idaho fescue and rough fescue to a single application of water (day 0). The ordinate represents the percent of the maximum growth rate (per day) obtained.

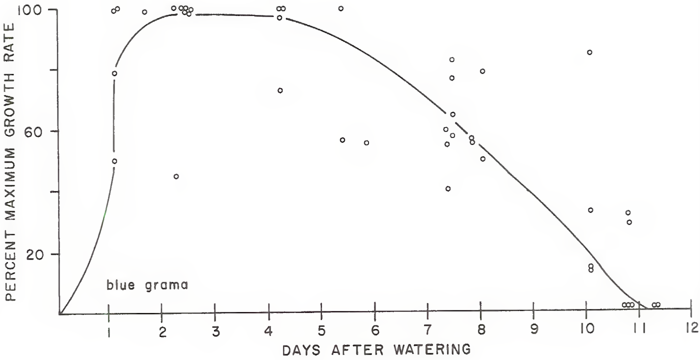


Figure III-15. The growth response of blue grama to a single application of water (day 0). The ordinate represents the percent of the maximum growth rate (per day) obtained.

Data for little bluestem and big bluestem are still receiving preliminary processing.

Quick response to frequent showers will be of competitive advantage to plants only if showers are large enough. If frequent showers are too light, species which respond quickly will remain in the high respiratory dehardened phase, and due to lack of water they will photosynthesize too little to match their respiratory losses. If occasional showers are moderate, plants which respond to watering quickly will be favored; significant growth will occur in the post-shower periods. If showers were both frequent and moderate, factors other than water (e.g., light and nitrogen) might become limiting.

CHAPTER IV

GENERAL

Citizens Advisory Committee

Larry Holman

A local Advisory Committee was organized last year, composed of seven members. Six members were selected by suggestion of the County Commissioners in Custer, Prairie, and Rosebud Counties. The seventh committee member was chosen to represent irrigated agriculture.

The Advisory Committee's purpose is basically twofold:

1. To provide guidance and input to help reduce uncertainties of experimental activities as related to the local agricultural interest. The committee provides direction to project operations in situations where public sentiment might exhibit concern towards the program activities.

2. To become well-informed on research goals and activities and convey its understanding of program functions to a concerned community.

Members of the committee are:

<u>Prairie County</u>

John Pehl
SE of Terry
Terry, MT 59349

Lawrence Keltner
Terry, MT 59349

<u>Custer County</u>

S.F. Mathers
2220 Pearl
Miles City, MT 59301

Buford Griffin
Locate, MT 59340

Harold J. Watts
Kinsey, MT 59338

<u>Rosebud County</u>

Omer C. Erickson
NW of Forsyth
Forsyth, MT 59327

Chester Larsen
Rosebud, MT 59347

Clerical Activities

Marian Waarvik, Ann Losinski, Mary McMinn and Mary Jo Stabio

Field season activities for clerical personnel were extensive and diversified. Responsibilities included cataloguing of rainfall and radar data; either storing it for later reduction or transferring it to another

facility for reduction or participating in its reduction. Associated with these tasks were basic computer operations.

On an annual basis, an awareness of personnel activities, daily records, arranging and scheduling of motels and plane reservations, required both time and an ongoing account. As part of public involvement, greeting of visitors, as well as conducting tours and explaining activities often became clerical responsibilities.

Other clerical tasks included maintaining supplies for project personnel, preparing for and assisting with employment of temporary personnel, learning state and federal regulations and procedures, and typing or drafting reports and publications.

Two data clerks were available during all of 1976 with a third during the latter half of the year to assist both the State and Federal staff.

Approximately 80 percent of the data clerk efforts were associated with meteorological activities and 20 percent with agro-ecological activities. Tables IV-1 and IV-2 outline the duties of the data clerks during 1976 and indicate the approximate percentage of time devoted to each.

TABLE IV-1

Percentage of time spent at each data clerk function associated with meteorological activities

Function	Percentage of Time
Reduce rain gage data	40
Type rain data on computer tapes	35
Wrap and catalog hail pads	8
Plot rain data	5
Plot aircraft flights	4
Work on monthly precipitation tables	2
Cut and tape ice crystal pictures in sequence	2
Miscellaneous	4
TOTAL	100

TABLE IV-2

Percentage of time spent at each data clerk function associated with agro-ecological activities

Function	Percentage of Time
Plot and correct data	10
Canopy Catch study	30
Prairie County plots (graphing and planimeter)	20
Clip ecology sites	10
Clerical	15
Miscellaneous	15
TOTAL	100

Facility Maintenance and Repair

Larry Holman and Herb Craig

Facility Maintenance and Upkeep. Much effort was expended in maintaining headquarter facilities, such as cleaning and painting, organizing and maintaining storage areas, and repairing facilities. Laborers assisted with chores requiring physical effort, such as loading and unloading materials and installing equipment.

Equipment Service and Repair. Transmission line problems, often plaguing computer operations during the field season, were handled with continuous cooperation from personnel of Mountain Bell and the Cyber 74-28 computer facility. Minor hardware problems with computer terminals were remedied with replaced parts.

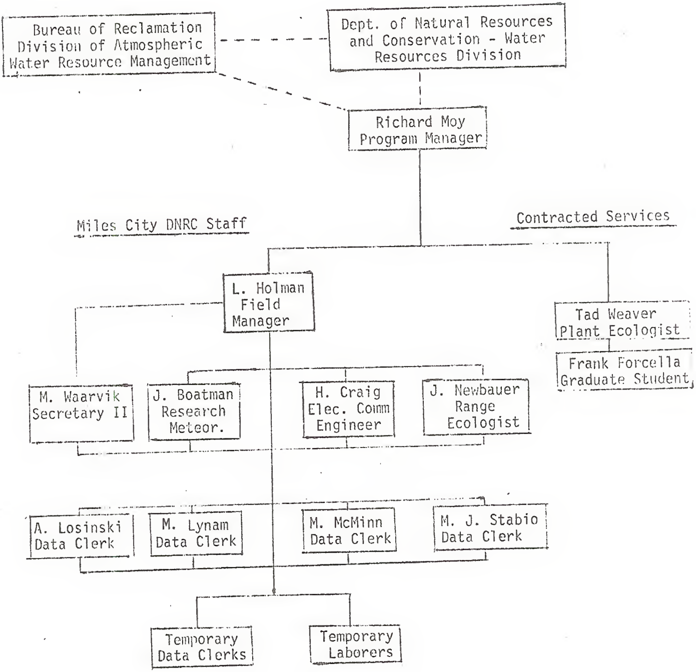
The limited range of the radios during 1975 prompted the installation of two new high-gain antennas. All project radios were properly aligned with the aid of Bureau of Reclamation personnel.

The RD-65 rawinsonde equipment was examined and adjusted prior to installation.

All four state leased vehicles were serviced on a regular and orderly basis to prevent abnormal wear. Only minor problems were encountered.

Appendix I

MONTANA HIPLEX STAFF ORGANIZATION CHART



APPENDIX II

Note: Use calibration weight set 8849, Gp. 1 for 12" rain gage.

CALIBRATION PROCEDURE FOR
12" DUAL TRAVERSE RAIN GAGE
CAT. No. 5-780

Refer to Fig. A-II-1

1) Set instrument on a level table.

2) Make the following preliminary adjustments;
   a) Set the one extension levers (30) to center of slots: tighten nuts (8) and adjusting screws (7).

   b) Center thread of fine adjustment screw (36).

   c) Set lower calibration slide (14) at extreme lower postion; tighten screws (15 and 16).

   d) Put equivalent bucket weight (1Kg) on center of bucket platform (6); keep this weight on the platform during entire calibration operation.

   e) Loosen set screw (21) of swivel bracket (17), adjust pen arm (18) so that it will be in line with pen arm bracket (20), and tighten set screw (21).

   f) Loosen set screw of counter weight lever (13), adjust this lever so that it will be in line with pen arm (18), check that front lever link (9) is perpendicular to instrument base, and tighten set screw (32).

3) Put six-1-inch weights (822.7 grams each) on center of bucket platform (6).

4) Pull out the three stop screws (2, 26 and 28) just enough to permit free full travel of movement bracket (3).

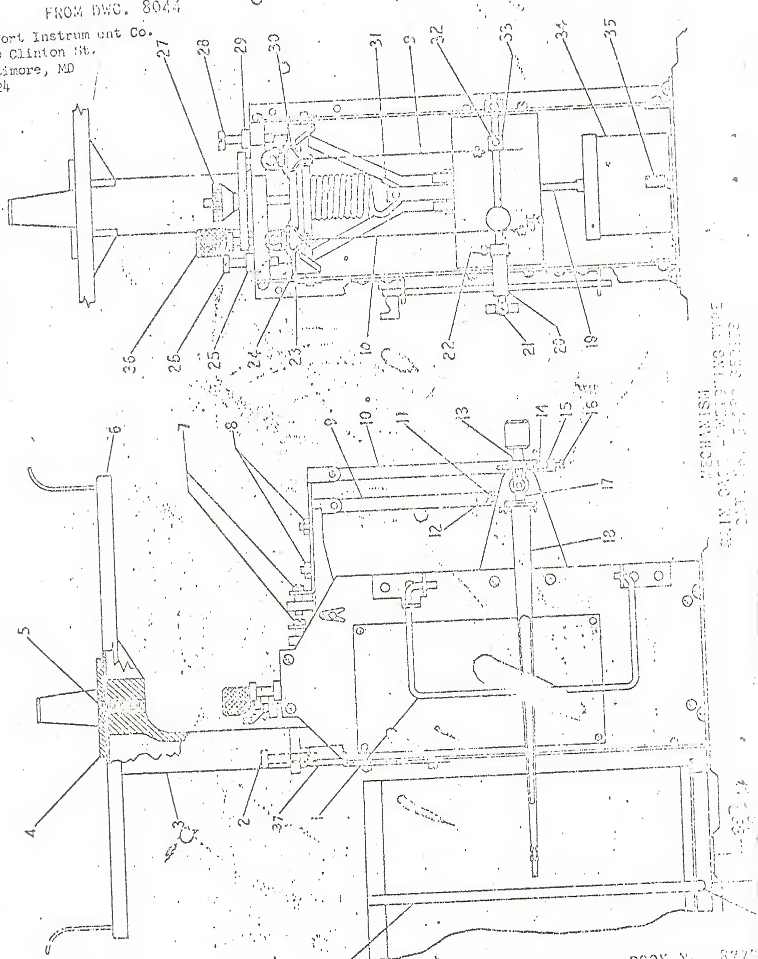
5) Level top lever (24) with thumb nut (27); use a small level.

6) Take off one 1-inch weight.

7) Swing out pen shift lever (1), twist riveted pen arm support of swivel bracket (17) so that the pen arm (18) falls lightly against the shift lever (1).

FROM DWG. 8044

Belfort Instrument Co.
2600 Clinton St.
Baltimore, MD
21224



BOOK No. 877

FIG. A-11-1

8) Loosen screw (12) of upper calibrating slide (11). Position and hold pen (18) on the 5" line of chart, make sure that the slide (11) is resting directly on the pivot screw of short lever (33), and tighten screw (12) of slide (11).

9) Remove all 1-inch weights.

10) Instrument is ready to be calibrated on the 0" to 6" range. Moving out the rear extension lever (30) will increase the range of travel of pen arm (18), and vice versa; one turn of the adjusting screw (7) is approximately equivalent to 0.05" (1 division) at the 5" line of the chart. Tighten nuts (8) and adjusting screw (7) after each adjustment of rear extension lever (30). Tap lightly on the bucket platform (6) while reading the positions of the pen on the chart.

11) With the equivalent bucket weight only on center of bucket platform (6), adjust pen (18) to exactly the 0" line of the chart by means of thumb nut (27) and/or fine adjustment screw (36).

12) Put five 1-inch weights, one at a time; note pen positions as you put weights. Pen should come to the 5" line.

13) Adjust rear extension lever (30) as required (see step 10); remove five 1-inch weight and repeat calibration starting from step 11, inclusive.

14) If pen is off at the intermediate postions (1", 2", 3" and 4"), loosen set screw (32) of short lever (33) and adjust the position of this lever, up or down, until the readings at the intermediate positions are correct. Repeat calibration starting from step 11, inclusive.

15) After calibration on the 0" to 6" range is finished , the instrument is ready to be calibrated on the 6" to 12" range. Moving out the front extension lever (23) will increase the range of travel fo pen arm (18), and vice versa; One turn of the adjusting screw (7) is approximately equivalent to 0.05" (1 division) at the 12" line of the chart. Tighten nuts (8) and adjusting screw (7) after each adjustment of front extension lever (23). Tap lightly on the bucket platform (6) while reading the position of the pen on the chart.

16) With a total of seven 1-inch weights on center of bucket platform (6), position of lower calibrating slide (14) so that pen (18) reads exactly 7" on the chart after screws (15 and 16) of slide (14) are tightened.

17) Put on five more 1-inch weights, one at a time note pen positions as you put on weights. Pen should come to the 12" line.

18) Adjust front extension lever (23) as required (see step 15); remove five 1-inch weights and repeat calibration starting from step 16, inclusive.

19) If pen is off at the intermediate positions (8", 9", 10" and 11"), loosen set screw of counter weight lever (13) and adjust the position of this lever, up or down, until the readings at the intermediate postions are correct. Repeat calibration starting from step 16, inclusive.

20) Calibrating tolerances are plus or minus 0.025" (1/2 division) on the 0" to 6" range, and 0.05" (1 division) on the 6" to 12" range.

21) When the calibration is complete, adjust stop screws (2) and (28) so that the pen will set halfway between the 0" line of the chart and the flange of the cylinder, at both ends of the travel of movement bracket (3). Insert shipping stop (37) on rear stop screw (2), and tighten front left stop screw (26). Tighten all stop screw locknuts.

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